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QUARTERLY RELIABILITY STATUS REPORT (U)

NAS9-150

30 June 1964

apollo

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QUARTERLY RELIABILITY STATUS REPORT (U)

NAS9-150

30 June 1964

Exhibit I, Paragraph 7.3

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

[redacted]

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FOREWORD

A quarterly report review was held at S&ID on 15, 16, and 17 June 1964. Many of the questions raised during this review are answered in this report. Additional information will be provided in subsequent quarterly reports, the Apollo Reliability Program Plan, and separate correspondence, in response to the NASA Letter PR-2-64-448, dated 21 July 1964, Subject: Contract NAS9-150, NAA S&ID's Eighth and Ninth Quarterly Reliability Status Reports.

The information contained in this report was prepared by Apollo Reliability Engineering to provide status on Reliability activities for the period 15 March 1964 to 15 June 1964.

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ILLUSTRATIONS

TABLES

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I. PROGRAM IMPLEMENTATION

BOILERPLATE 12

INTRODUCTION

Prior to the flight of Boilerplate 12, all requirements for minimum airworthiness of mission essential equipment had been satisfied or exceeded. All on-board systems had been examined for both quality of redundant equipment and existence of possible single-point failures. Where potential single-point failures did exist, investigation revealed that the probability of failure was sufficiently low to warrant the acceptance of the systems. The one critical area was the functioning of the single drogue parachute. However, analysis showed that the parachute had been designed with wide loading margin. Since redundant initiation was provided to ensure the firing of the deployment mortar, the risk associated with this possible single-point failure was sufficiently low to be acceptable. Future vehicles, however, will have two drogue parachutes.

DISCUSSION

During the flight of Boilerplate 12, all but a few components operated satisfactorily with the instrumentation supplying useful data. Significant equipments that did not perform as required are indicated in the following discussion of deficient equipment operation during the flight.

Loss of One Main Parachute

The loss of one main parachute occurred when the riser was cut during deployment. This cannot be attributed to a parachute or riser deficiency, nor to the system operation, but to a combination of two specific conditions. First, there had to be a sharp edge to cut the riser, and second, the riser had to come in contact with this edge. Because of the extreme oscillations of the vehicle while on the drogue parachute, the riser was pulled across the non-structural dummy RCS engine, bending it out of the way. This enabled the riser to work in behind the dummy engine and contact a ragged edge on the expended drogue disconnect. The incorporation of a second drogue should do much to alleviate the oscillations which contributed to this condition. Subsequent vehicles, which will include the dual drogue, will also have incorporated structural protection around the RCS engine, precluding a repetition of this type of failure.

Split Gore in Main Parachute

Immediately after disreefing, a single gore in one of the two remaining parachutes split from the skirt to the vent. The 19,000-pound load on this parachute was considerably under the ultimate design load of 32,000 pounds. The parachute is being examined to determine whether the fabrication was in compliance with applicable specifications and drawings. Despite its condition, the parachute did perform its intended function within specified limits.

Premature Timeout of 41-Second Timers

The premature timeout of both 41-second timers in channel "A" occurred immediately after Little Joe II thrust termination. A dropout of power for a time duration of 10 to 50 milliseconds after an R-C network charging time of 25 seconds will cause the timer to activate upon reinstatement of power. It is believed that the system "A" logic hot-line circuit grounded to Little Joe II structure at thrust termination. Separation of the command and service modules broke this short almost immediately. These timers were a backup for the radio command signal that initiates both thrust termination and abort initiation. Since the radio command did work and the resulting thrust termination caused the dropout which precipitated the failure, it seems that the timers would have worked satisfactorily had they been needed.

Instrumentation Problems

For the Boilerplate 12 flight test, 138 flight measurements were planned. Satisfactory data were produced by 122 measurements. Ten measurements produced satisfactory data for part of the flight duration, and six produced no data at all. The cause of the malfunctioning of 12 of these measurements has been determined, and the analysis of three is continuing. One system, lost through jettison of the launch escape system, will be evaluated by assessment of the design, and, if necessary, by simulation.

Details of the 16 unsatisfactory measurements are as follows:

1. One camera mounted in the service module was never found. Fragments of the camera support were located near the Little Joe II debris, indicating the camera was detached at abort.

2. A camera mounted in the command module ran so slowly that it drew excessive current and the motor overheated. The cause is being investigated.

3. The camera mounted in the launch escape tower did not operate. Ninety-eight percent of the film remained unused. Cause of the jamming is being investigated.

4. All three attitude gyros experienced gimbal lock during the flight. The roll gyro locked when the pitch attitude exceeded 80 degrees. The yaw and pitch gyros locked when the roll attitude exceeded 80 degrees. It is recommended that Little Joe II roll control be incorporated on future flights.

5. Four base pressure measurements were lost by the effects of the Little Joe II destruct. Two had the lines to their orifices damaged, and two lost power through damage to electronic circuitry, causing a fuse to blow.

6. Three fluctuating pressure measurements were lost by the effects of the Little Joe II destruct. Impairment of bridge circuits caused one to indicate maximum signal, and the other two to indicate zero signal.

7. Two surface pressure measurement transducers lost accuracy late in the flight. One began registering a gradually increasing pressure after 60 seconds and registered a high pressure of 1.2 psi by flight termination. No cause is known and the transducer is being recalibrated. The other one registered a constant 4 psia after operating satisfactorily for 44 seconds. It is believed that a flex line to the pressure port kinked when the forward cover was jettisoned.

8. A pressure measurement in the launch escape motor chamber provided no data because the sensing element was lost when the LES was jettisoned.

In summary, all problems and nonconformances experienced on this flight are being investigated by Reliability in conjunction with the design groups.

BOILERPLATE 13

Summaries of the departmental efforts to assure a successful launch and flight were presented in the Boilerplate 13 Reliability Flight Readiness Report. It included (1) recommendations for launch readiness; (2) a qualitative evaluation of each of the systems comprising the spacecraft; (3) the identification and significance of single-point failures within systems whose successful operations are essential to the completion of primary mission objectives; (4) the current status of equipment airworthiness testing; and (5) the corrective action provided to date on nonconformance reports. After the satisfactory completion of the minimum airworthiness testing of the mission sequencer and with the absence of any significant anomalies in electrical system checkout during countdown, Boilerplate 13 was accepted for launch.

The only reported anomalies during the countdown and flight were as follows:

1. Unaccountable noises from the cooling system pump were noted during the final countdown, with indications of excessive current usage and low outlet pressure. However, the cooling system exceeded mission requirements during the flight. Future pumps will incorporate design review suggested changes to increase reliability and preclude possible failure modes observed during Boilerplate 13 operations.

2. Three calorimeter measurements on the service module failed to function, one strain gage on the adapter dropped out for 13 seconds, and a service module vibration measurement was lost after 46 seconds of flight. Reasons for these failures are under investigation. The remaining 111 measurements performed satisfactorily.

INTEGRATED TEST SUPPORT

Reliability test support was given to the test preparation area, the Florida and WSMR facilities, for Boilerplates 12, 13, and 15. This effort involved reviewing test procedures, monitoring tests, and processing and routing nonconformance reports for corrective action, with analyses of failed hardware performed in the assessment areas. Reliability problems occurring at the field sites were analyzed, and their solutions were sent to the field.

PROPOSED ACTIVITIES

Review of plans for the propulsion system development facility is underway. Inputs are being generated for the Reliability section of the post-flight test report for Boilerplates 12 and 13. These reviews and reports will be completed during the next quarter.

Tests and checkouts on Boilerplates 14 and 23 and Airframe 001 will be monitored. Deviations and problems detected during the test and checkout period will be analyzed, and corrective action will be initiated when required to assure the successful completion of the vehicles' missions. A critique of the test and checkout procedures will be made to assure their adequacy.

SUPPLIER SURVEILLANCE

The evaluation and approval of supplier or subcontractor capabilities for the Apollo program continue under close surveillance of Apollo Reliability Engineering. Supplier pre-award surveys are conducted to assure that supplier and subcontractor reliability capabilities are consistent with overall system requirements.

Subsequent to the last reported summary of supplier surveys, 23 pre-award surveys, including one resurvey, were made. The companies surveyed, their locations, and the Apollo procurement involved are summarized in Table 1-1. A total of 200 surveys have been conducted to date.

Table 1-1. Supplier Surveys

Equipment	Name	Location
Measurement set, optical properties, space radiation	Barnes Engineering Co.	Stanford, Conn
Measurement set, optical properties, space radiation	Lyon Research, Inc.	Cambridge, Mass
Flexible linear shaped charge	Ensign - Bickford, Inc.	Simsbury, Conn
Flexible linear shaped charge	Explosive Technology, Inc.	Santa Clara, Calif
Detonator cartridge assembly	Ordnance Systems Branch, Librascope Division, General Precision	Sunnyvale, Calif
Connector assembly	General RF Fitting Co.	Boston, Mass
Connector assembly	ITT Cannon Electric, Salem Division	Salem, Mass
Connector assembly	Gremar Inc.	Wakefield, Mass

Table 1-1. Supplier Surveys (Cont)

Equipment	Name	Location
Flow transducers	Gulton Industries, Instrumentation Division	Metuchen, N.J.
Flow transducers	Flow Technology	Tempe, Ariz
Flow transducers	Tylan Corp.	Gardena, Calif
Pressure transducers	Wiancko Engineering Division, Tamar Electronics, Inc.	Pasadena, Calif
Circuit breakers	Mechanical Products	Jackson, Mich
Circuit breakers	Texas Instruments, Metal & Controls Division	Attleboro, Mass
Displacement transducers	Data Sensors, Inc.	Gardena, Calif
Hermetically sealed pushbutton switch	Haydon Switch, Inc.	Waterbury, Conn
Hermetically sealed pushbutton switch	Jay-El Products, Inc.	Gardena, Calif
Hermetically sealed pushbutton switch	Korry Mfg. Co.	Seattle, Wash
Resistance temperature sensor	Temtech, Inc.	Santa Ana, Calif
Pulse code modulation system	Gulton Industries, Electronics Division	Albuquerque, N.M.
Pulse code modulation system	Vector, Dept of Norden, Division of United Aircraft	South Hampton, Penn
Pulse code modulation system	Dynatronics, Inc.	Orlando, Fla
Resurvey	Fairchild Controls	Hicksville, N.Y.

RELIABILITY PROGRAM EVALUATION AUDIT

Reliability audits of subcontractors and suppliers have been performed to determine the effectiveness of their reliability program implementation. Deficiencies noted were brought to the attention of those concerned, and follow-up action is being taken to assure resolution of all deficiencies. Table 1-2 lists the audits performed during the report period.

Table 1-2. Reliability Program Evaluation Audit

Apollo Equipment	Subcontractor/Supplier	Location
Data storage equipment	Leach Corp, Controls Division	Azusa, Calif
Service module reaction control system	Marquardt	Van Nuys, Calif
Earth landing system	Northrop-Ventura	Newbury Park, Calif

DESIGN REVIEW STATUS

Table 1-3 summarizes the Apollo design review activity conducted during the last quarter.

Table 1-3. Apollo Design Review Status

No.	Review Subject	Type of Review	Date Conducted	Approval Status
14	Crew couch design and mechanical systems	Major	3-31-64	Approved
32	C14-240 service equipment ACE spacecraft adapter	Major	4-3-64	Withheld*
28	C-band transponder	Prelim	3-30-64	Approved
31	Stabilization and control system	Prelim	4-14-64	Approved
37	S14-057, 063, 064 RCS fuel and oxidizer servicing units	Major	5-25-64	Approved
38	CM inner structures	Major	3-20-64	Approved
39	Fuel cells	Major	4-10-64	Approved
40	SPS engine	Major	3-25-64	Withheld*
41	CM heat shield substructure	Major	3-24-64	Approved
43	S14-054 EPS cooling servicing unit	Major	3-19-64	Withheld*
44	CM system support structure	Major	3-26-64	Approved
45	Audio center	Prelim	5-21-64	Approved

Table 1-3. Apollo Design Review Status (Cont)

No.	Review Subject	Type of Review	Date Conducted	Approval Status
46	VHF/UHF 2-kmc omni-antenna	Prelim	4-13-64	Approved
47	BP 16	Prelim	3-16-64	Approved
48	Entry and post-landing batteries	Prelim	4-24-64	Approved
49	BP 12	Preflight	4-13-64	Approved
51	BP 13	Preflight	5-8-64	Approved
52	C-band operational beacon antenna	Prelim	4-2-64	Approved
53	C14-212, 214, 215 ACE signal conditioning equip	Major	5-19-64	Withheld*
55	S14-060, 061 toxic vapor disposal units	Special	4-15-64	Approved
56	Recovery antenna	Prelim	4-27-64	Withheld*
57	Battery charger, vent line and control assembly	Prelim-Major	4-24-64	Approved
58	Signal conditioner	Prelim	5-15-64	Approved
59	Launch escape and pitch control motors	Major	5-25-64	Approved
60	BP 27	Prelim	5-21-64	Approved
61	C14-009	Special	4-14-64	Approved
62	PCM telemetry	Prelim	5-28-64	Approved
63	ECS pump for BP 13	Special	5-15-64	Approved

*See discussion following the table.

SERVICE EQUIPMENT ACE SPACECRAFT ADAPTER

Approval was withheld on the C14-240, servicing equipment, ACE spacecraft adapter, because the design reliability estimate is less than half of the reliability required of the system. The reliability can be improved by reducing maintenance time or incorporating redundancy for priority data. Operational requirements are now firm, and the reliability and maintainability conditions will be re-evaluated. When the re-evaluation is complete, GSE Design will incorporate the assurance that the reliability requirements are met, and the system will be re-reviewed to obtain Design Review Board approval.

SPS ENGINE

Approval was withheld on the SPS engine pending resolution of several problem areas still undergoing development modifications by Aerojet. These problems involve design of the injector thrust chamber and the bi-propellant valve. When Engineering approves these changes as acceptable for pre-qualification testing, a special review will be held to obtain Board concurrence.

FUEL CELL POWERPLANT WATER-GLYCOL SERVICING UNIT

Board approval of the S14-054, fuel cell power plant water-glycol servicing unit, was withheld for the following reasons.

1. There is a possibility of eliminating the GSE S14-054 by sharing the GSE S14-019 ECS water glycol servicing unit, thus reducing the cost of Apollo program.

2. It is impractical to evacuate the fuel cell coolant system to 10^{-2} mm Hg to obtain 100-percent water-glycol fill, while the subject GSE is located 350 feet away.

3. Redesign of the S14-054 may be necessary to withstand approximately 250 psig working pressure in lieu of the current design working pressure of 60 psig. The location of the subject GSE is some 300 feet below the spacecraft fuel cell coolant system (static head of 300 feet = 150 psig).

4. A redesign of the S14-054 may still be required in order to supply the 100 psig to the spacecraft fuel cell coolant system, even if the GSE could be relocated to the service module service platform.

5. Remote control and explosion proof are not requirements. The deletion of these two requirements represents a major portion of the electrical circuitry and approximately 15 percent of fluid system hardware.

6. Change of the pumping rate from 1 to 10 gpm will be required to satisfy the fuel cell coolant system specification for flushing capability. This change will create the problem of holding the water-glycol tank and water tank capacities versus pumping rate ratios to 10 to 1.

When studies regarding the preceding items are completed, a review will be held for Board evaluation of the changes instigated.

ACE SIGNAL CONDITIONING EQUIPMENT

Design Review Board approval was withheld on the ACE signal conditioning equipment for the following reasons.

1. The equipment may be installed at T-72 hours and removed at T-5 hours. During this time, the portable life support system, fecal canister, and center couch will be in position. The interference problem is such that it is impossible to install and remove the ACE signal conditioning equipment.

2. The predicted MTBF of 59 hours with 62 hours of operating time requires an improved method of fault isolation and maintainability in order to repair a defective submodule in 15 minutes. Drawer level sparing is required. This concept is under investigation.

When these items are changed and incorporated, the models will be reviewed to obtain Board approval.

RECOVERY ANTENNA

Approval of the recovery antenna was withheld pending resolution of the following items.

1. The present method of attaching the backup recovery antenna presents a potential crew safety hazard, because of the possible 600 F temperature in the planned area of installation.

2. A potential interference problem between the recovery antenna equipment and parachutes, including the feasibility of relocating the antenna base, requires investigation.

3. Procurement Specification (MC 481-0002) requires revision for the antenna to meet +400 F temperatures instead of the present +200 F (para. 3.5.2(a)).

After incorporation of these recommendations, the system will be reviewed to obtain Design Review Board approval.

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TRAINING AND EDUCATION

SUMMARY

Reliability technical courses, seminars, and symposia presented during the report period are shown in Table 1-4.

Table 1-4. Reliability Education

Title	Number of Presentations	Average Attendance	Total Student Hours
Fundamentals of Reliability Mathematics Course	6	10	87
Design Analysis Techniques Course	21	18	547
Computer Methods of Analysis Course	13	9	171
Symbolic/Boolean Logic Course	1	12	18
Statistical Aspects of Reliability Course			
Seminars			
Symposia			
TOTAL	41	49	823

Approximately 200 of the following publications were sent out to S&ID departments during the report period:

Symbolic/Boolean Logic

Fundamentals of Reliability Mathematics

Reliability Techniques and Applications for Design Analysis (Volumes I and II)

[redacted]

The proposed bulletin "T&QA/Reliability Review " was approved by the Division Director of Test and Quality Assurance. This technical publication will be published as required and bring pertinent reliability information to the desk of the engineer.

PLANNED ACTIVITIES

A symposium for instrumentation suppliers is to be held after the instrumentation specification is completed. Approximately twenty instrumentation suppliers are expected to be under contract at this time. Two in-house reliability seminars for instrumentation engineers are currently in preparation.

TECHNICAL INTEGRATION

DATA SYSTEMS DEVELOPMENT

Traceability and Configuration (TAC) Mechanized System

Conversion from the interim TAC system to the final system is complete. The system provides printouts of the as-built configuration by indenture level sequence and reports comparing the as-built to the as-designed configurations. Special emphasis is being placed on encoding, processing, and producing reports for Boilerplate 15.

Nonconformance Report (NCR) System

The Phase II program (NCR report generator) is producing periodic and special reports in response to NAA and NASA requests. Approximately 370 reports were produced and distributed for use by Reliability and Quality and Logistics engineering groups. Weekly reports have increased from three to ten. Monthly reports have increased from seven to 15.

Operating Time (O/T) System

Phase I programming of the operating time system is complete. A system checkout program of pseudo test data is being developed to simulate various input conditions and to flag the resulting output reports for performance evaluation. The testing program is scheduled to be completed and implemented during June 1964.

Parameter and Test History (PATH) System

The revision PATH "Inspection and Test Record" form is being finalized, and a usage training program is being initiated. Tests are currently in progress to ascertain that the present form meets all PATH data requirements. The encoding responsibilities have been established and are being coordinated with the responsible groups. The programming of the PATH system has indicated that the current definition limitations could be expanded to handle more data.

CVR/CCR Mechanized System

This new system has been programmed to incorporate all EO's within the CVR and CCR books. The printouts show the status of each EO. They indicate if the EO has been worked off, superseded, removed, or cancelled, or if it is still outstanding. At the present time, the system includes encoded data for Boilerplates 13, 14, 15, and 23, and many GSE end items. All computer programming for this system is essentially complete and in the operational stage. The programs also provide the ability to compute data processing charges to individual projects.

Quality History (QH) and SQUAWK Systems

Technical Integration Data Systems and Apollo Data Control Center groups continue to coordinate with the Quality Engineering Laboratories, Survey and Corrective Action Group, to operate, develop, and improve the quality indicators reporting. The quality indicators program utilizes the quality history and SQUAWK data systems to report actual quality levels and to determine quality trends and the need for special investigations and analyses in the manufacturing shops.

Quality Engineering Laboratory (QEL) uses the quality indicators reports to monitor manufacturing. QEL furnishes staff quality engineers to conduct special investigations and analyses, and to initiate corrective action in the shops.

Supplier Quality History (SQH)

The supplier quality history rating system was used to perform corrective action on delinquent suppliers. They were required to bring their product up to acceptable standards or be removed from the approved status. Approximately twelve suppliers were visited and others were contacted by letter and telephone. The volume of data in the SQH system is reaching a level sufficient to utilize full capability of the system.

Interservice Data Exchange Program (IDEP)

Approximately 375 IDEP reports requested by Project Apollo engineers were distributed, and approximately twenty-five Apollo S&ID originated reports were forwarded to the Air Force IDEP control center. Information bulletins listing IDEP reports on Projects Mercury and Gemini were compiled and distributed to cognizant engineering groups. An audio visual presentation outlining the purpose, functions, and benefits of IDEP was shown to approximately fifty Apollo engineers.

APOLLO DATA CONTROL CENTER

Nonconformance Reports (NCR)

A total of 3663 nonconformance reports (NCR) were reviewed, evaluated, analyzed, processed, and transposed to transmittal sheets to be stored by Data Processing on magnetic tapes for reference and mechanized retrieval. Printouts showing weekly, monthly, and specific component tabulations and accumulated monthly NCR activity are being distributed regularly to cognizant engineering groups. Qualitative and quantitative summary problem reports have been prepared and issued, showing the distribution of various nonconformance conditions by vehicle subsystem.

Subcontractor and Supplier Data Activities

The flow of supplier failure reports to S&ID is increasing. 803 problem reports were received, reviewed, and processed for storage and retrieval in the data bank. Monthly failure summaries delineating problem, cause, part condition, trends, analysis of problem, and required corrective action taken, are prepared and issued to functional groups. As specific supplier hardware trends develop, individual quantitative and qualitative reports will be prepared and distributed to cognizant groups.

SCRAP REPORT

Nine hundred and ninety-one scrap reports involving 2954 parts were processed, tabulated, and issued as monthly summary reports. The scrap report summaries list items that are reported through the nonconformance reporting system. The parts with significant scrap rates were coldplates (158), initiators (328), electrical wire (15,350 feet), electrical boards (181), and AND gates (140).

COMPONENT TECHNOLOGY

APPLICATION DATA, PREFERRED PARTS

A recommended procedure for selecting discrete resistor types and values from the extremely large number available has been prepared. It includes a listing of worst-case resistor tolerances (suitable for use in worst-case computer circuit analysis), mechanical data, failure rates, and temperature coefficients. Tables 1-5 and 1-6 are the summary sheets for resistors. These are the result of extensive studies conducted to define anticipated parametric drifts and a logic for resistor logic selection.

Training and indoctrination courses have been given to source inspection personnel. These courses inform the involved inspection personnel on the preferred parts program and detailed parts requirements.

Summary sheets for major usage parts are in various stages of completion and provide configuration, parameter, parameter drift, and failure data for each component in the preferred parts program.

PLANNED ACTIVITY

Component Technology will continue to provide Apollo Reliability with technical assistance on piece parts. This includes meetings with subcontractors and suppliers, reviews of subcontractor specifications, and part technical consultation services.

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Table 1-5. Resistor Electrical Data Summary

TYPE PART NO. W A T T S	% T O L.	ME 443- DASH NO.	ELECTRICAL DATA: RATINGS — RESISTANCE RANGE OHMS	θ TR °C/W	TC PPM/°C	FULL PWR °C	ZERO PWR °C	3 YEAR WORST CASE RESISTANCE TOLERANCE - ±%: TC PPM/°C	3 YR ΔR %	0% POWER -40 °C	0% POWER 25 °C	0% POWER 125 °C	50% POWER -40 °C	50% POWER 25 °C	50% POWER 125 °C	100% POWER -40 °C	100% POWER 25 °C	100% POWER 125 °C	MECHANICAL DATA L	MECHANICAL DATA D	F.R. %/1000 HRS 90% CONF.	REMARKS
HIGH RELIABILITY RESISTORS - ESTABLISHED RELIABILITY - TRACEABLE BY LOTS - HIGHEST QUALITY STATE-OF-ART																						
METAL FILM - MOLDED OR CONFORMALLY COATED																						
1/8	1.0	0060	30.1 Ω to 499 K	45	25	125	170	25	1.0	2.16	2.00	2.25	2.10	2.05	2.30	2.04	2.11	2.36	0.375	0.125	0.01	Recommended for use in critical application in airborn systems. Good frequency characteristics up to 100 Mc. Very good stability.
1/4	1.0	0061	51.1 Ω to 1.00 M	45	25	125	170	25	1.0	2.16	2.00	2.25	2.10	2.05	2.30	2.04	2.11	2.36	0.625	0.188	0.01	
1/2	1.0	0062	51.1 Ω to 1.50 M	45	25	125	170	25	1.0	2.16	2.00	2.25	2.10	2.05	2.30	2.04	2.11	2.36	0.750	0.250	0.01	
1.0	1.0	0063	51.1 Ω to 3.92 M	45	25	125	170	25	1.0	2.16	2.00	2.25	2.10	2.05	2.30	2.04	2.11	2.36	1.063	0.375	0.01	
2.0	1.0	0064	51.1 Ω to 10.0 M	45	25	125	170	25	1.0	2.16	2.00	2.25	2.10	2.05	2.30	2.04	2.11	2.36	2.188	0.375	0.01	
METAL FILM - HERMETICALLY SEALED																						
1/8	1.0	0138	10.0 Ω to 200 K	50	100	125	175	100	0.5	2.15	1.50	2.50	1.90	1.75	2.75	1.64	2.00	3.00	0.281	0.155	0.01	Same as above
PRECISION WIREWOUND																						
1/8	0.1	0073	1.00 Ω to 100 K	20	15	125	145	15	0.2	0.39	0.29	0.44	0.38	0.31	0.46	0.36	0.32	0.47	0.310	0.250	0.005	Very good stability. Tight initial tolerance and low drift. Not recommended for use above 5.0 Kc.
1/4	0.1	0074	1.00 Ω to 1.00 M	20	15	125	145	15	0.2	0.39	0.29	0.44	0.38	0.31	0.46	0.36	0.32	0.47	0.500	0.250	0.005	
1/2	0.1	0127	1.00 Ω to 3.97 M	20	15	125	145	15	0.2	0.39	0.29	0.44	0.38	0.31	0.46	0.36	0.32	0.47	0.812	0.297	0.005	
1.0	0.1	0076	1.00 Ω to 4.99 M	20	15	125	145	15	0.2	0.39	0.29	0.44	0.38	0.31	0.46	0.36	0.32	0.47	1.000	0.500	0.005	
POWER WIREWOUND																						
2.0	1.0	0068	0.10 Ω to 16.2 K	250	20	25	275	20	1.0	2.56	2.70	2.90	2.11	2.25	2.44	2.36	2.50	2.70	0.810	0.187	0.1	Recommended for use in applications where very high body temperatures can be tolerated, and where relatively small physical size is desirable. * CHASSIS MOUNTED TYPES
5.0	1.0	0069	0.10 Ω to 11.8 K	250	20	25	275	20	1.0	2.56	2.70	2.90	2.11	2.25	2.44	2.36	2.50	2.70	0.880	0.312	0.1	
10.0	1.0	0107	1.00 Ω to 15.0 K	250	20	25	275	20	1.0	2.56	2.70	2.90	2.11	2.25	2.44	2.36	2.50	2.70	1.780	0.380	0.1	
10.0	1.0	0070*	1.00 Ω to 5.62 K	250	20	25	275	20	1.0	2.56	2.70	2.90	2.11	2.25	2.44	2.36	2.50	2.70	1.380	0.810	0.1	
25.0	1.0	0071*	1.00 Ω to 12.4 K	250	20	25	275	20	1.0	2.56	2.70	2.90	2.11	2.25	2.44	2.36	2.50	2.70	1.940	1.090	0.1	
50.0	1.0	0072*	1.00 Ω to 39.2 K	250	20	25	275	20	1.0	2.56	2.70	2.90	2.11	2.25	2.44	2.36	2.50	2.70	2.180	1.160	0.1	
GENERAL USAGE RESISTORS - NON-CRITICAL APPLICATION - NON-TRACEABLE - ECONOMY TYPES																						
CARBON COMPOSITION (INSULATED)																						
1/4	5.0	0109	2.7 Ω to 22 M	80	2000	70	150	2000	8.0	26.0	13.0	33.0	18.0	21.0	41.0	16.0	29.0	49.0	0.250	0.090	- - - -	Not recommended for use where a drift in the order of 25% to 35% cannot be tolerated. These units will not open or short.
1/2	5.0	0110	2.7 Ω to 22 M	80	2000	70	150	2000	8.0	26.0	13.0	33.0	18.0	21.0	41.0	16.0	29.0	49.0	0.375	0.140	- - - -	
1.0	5.0	0111	2.7 Ω to 22 M	80	2000	70	150	2000	8.0	26.0	13.0	33.0	18.0	21.0	41.0	16.0	29.0	49.0	0.562	0.225	- - - -	
2.0	5.0	0112	10 Ω to 22 M	80	2000	70	150	2000	8.0	26.0	13.0	33.0	18.0	21.0	41.0	16.0	29.0	49.0	0.688	0.312	- - - -	
CARBON FILM - SEALED																						
1/8	1.0	0079	5.11 Ω to 1.00 M	95	-500	70	165	-500	1.0	5.25	2.00	7.00	2.87	4.37	9.37	3.50	6.75	11.75	0.375	0.125	- - - -	Not recommended for critical application. Good frequency characteristics up to 100 Mc. Fairly good stability.
1/4	1.0	0080	10.0 Ω to 2.00 M	95	-500	70	165	-500	1.0	5.25	2.00	7.00	2.87	4.37	9.37	3.50	6.75	11.75	0.625	0.188	- - - -	
1/2	1.0	0081	10.0 Ω to 4.99 M	95	-500	70	165	-500	1.0	5.25	2.00	7.00	2.87	4.37	9.37	3.50	6.75	11.75	0.750	0.250	- - - -	
1.0	1.0	0082	10.0 Ω to 10.0 M	95	-500	70	165	-500	1.0	5.25	2.00	7.00	2.87	4.37	9.37	3.50	6.75	11.75	1.063	0.375	- - - -	
2.0	1.0	0083	30.1 Ω to 20.0 M	95	-500	70	165	-500	1.0	5.25	2.00	7.00	2.87	4.37	9.37	3.50	6.75	11.75	2.188	0.375	- - - -	
PRECISION WIREWOUND																						
1/8	0.1	0098	1.00 Ω to 100 K	20	30	125	145	30	0.5	0.79	0.59	0.89	0.76	0.62	0.92	0.73	0.65	0.95	0.310	0.250	- - - -	Not recommended for critical applications. See remarkes for PRECISION WIREWOUND (above)
1/4	0.1	0099	1.00 Ω to 1.00 M	20	30	125	145	30	0.5	0.79	0.59	0.89	0.76	0.62	0.92	0.73	0.65	0.95	0.500	0.250	- - - -	
1/3	0.1	0100	1.00 Ω to 2.00 M	20	30	125	145	30	0.5	0.79	0.59	0.89	0.76	0.62	0.92	0.73	0.65	0.95	0.750	0.250	- - - -	
1.0	0.1	0101	1.00 Ω to 4.99 M	20	30	125	145	30	0.5	0.79	0.59	0.89	0.76	0.62	0.92	0.73	0.65	0.95	1.000	0.500	- - - -	
POWER WIREWOUND																						
2.0	1.0	0093	0.10 Ω to 39.2 K	250	30	25	275	30	1.0	2.19	2.00	2.29	2.18	2.37	2.67	2.55	2.75	3.05	0.810	0.187	- - - -	Not recommended for critical applications. See remarks for POWER WIREWOUND (above). * CHASSIS MOUNTED TYPES
5.0	1.0	0094	0.10 Ω to 75.0 K	250	30	25	275	30	1.0	2.19	2.00	2.29	2.18	2.37	2.67	2.55	2.75	3.05	0.880	0.312	- - - -	
10.0	1.0	0108	0.10 Ω to 240 K	250	30	25	275	30	1.0	2.19	2.00	2.29	2.18	2.37	2.67	2.55	2.75	3.05	1.780	0.380	- - - -	
10.0	1.0	0095*	0.10 Ω to 34.8 K	250	30	25	275	30	1.0	2.19	2.00	2.29	2.18	2.37	2.67	2.55	2.75	3.05	1.380	0.810	- - - -	
25.0	1.0	0096*	0.10 Ω to 75.0 K	250	30	25	275	30	1.0	2.19	2.00	2.29	2.19	2.37	2.67	2.55	2.75	3.05	1.940	1.090	- - - -	
50.0	1.0	0097*	0.10 Ω to 237 K	250	30	25	275	30	1.0	2.19	2.00	2.29	2.19	2.37	2.67	2.55	2.75	3.05	2.180	1.160	- - - -	

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Table 1-6. Resistance Decade Values (100 to 1000 Ohms)

	A				D				C				D				B				D				C				D			
1/2% DECADE	100 147 215 316 464 681	101 149 218 320 470 690	102 150 221 324 475 698	104 152 223 328 481 706	105 154 226 332 487 715	106 156 229 336 493 723	107 158 232 340 499 732	109 160 234 344 505 741	110 162 237 348 511 750	111 164 240 352 517 759	113 165 243 357 523 768	114 167 246 361 530 777	115 169 249 365 536 787	117 172 252 370 542 796	118 174 255 374 549 806	120 176 258 379 556 816	121 178 261 383 562 825	123 180 264 388 569 835	124 182 267 392 576 845	126 184 271 397 583 856	127 187 274 402 590 866	129 189 277 407 597 876	130 191 280 412 604 887	132 193 284 417 612 898	133 196 287 422 619 909	135 198 291 427 626 920	137 200 294 432 634 931	138 203 298 437 642 942	140 205 301 442 649 953	142 208 305 448 657 965	143 210 309 453 665 976	145 213 312 459 673 988
1% DECADE	100 147 215 316 464 681		102 150 221 324 475 698		105 154 226 332 487 715		107 158 232 340 499 732		110 162 237 348 511 750		113 165 243 357 523 768		115 169 249 365 536 787		118 174 255 374 549 806		121 178 261 383 562 825		124 182 267 392 576 845		127 187 274 402 590 866		130 191 280 412 604 887		133 196 287 422 619 909		137 200 294 432 634 931		140 205 301 442 649 953		143 210 309 453 665 976	
5% DECADE	100 150 220 330 470 680								110 160 240 360 510 750								120 180 270 390 560 820								130 200 300 430 620 910							
10% DECADE	100 150 220 330 470 680																120 180 270 390 560 820															
20% DECADE	100 150 220 330 470 680																															

COLUMN A LISTS THE 20% DECADE VALUES WHICH ARE PREFERRED. PURCHASE TOLERANCE IS ± 20% OR BETTER

COLUMN B LISTS THE 10% DECADE VALUES WHICH ARE THE SECOND PREFERENCE. PURCHASE TOLERANCE IS ± 10% OR BETTER

COLUMN C LISTS THE 5% DECADE VALUES WHICH ARE THE THIRD PREFERENCE. PURCHASE TOLERANCE IS ± 5% OR BETTER

COLUMN D LISTS THE 2% DECADE VALUES WHICH ARE THE FOURTH PREFERENCE. PURCHASE TOLERANCE IS ± 2% OR BETTER

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II. ELECTRONIC SUBSYSTEM ANALYSIS

COMMUNICATIONS AND DATA

SUMMARY

Configuration and trade-off studies were performed for the Block II configuration effort. The subcontractor's reliability effort has been monitored via technical coordination meetings, program reviews, completion of scheduled audits, and correspondence to assure continued growth in the communications and data (C & D) subsystem reliability potential.

ANALYSIS

Recommended Configuration for AFRM 037

As a result of major changes in the requirements for in-flight maintenance in the guidance and navigation subsystem and in support of the effort to optimize the configuration of the C & D subsystem, a sparesweight optimization study of the electronic subsystems for the LOR mission was conducted.

The following recommendations were made based on the results of the study.

1. The unified S-band equipment should be made redundant.

2. The communications and data subsystem in-flight maintenance capability should be retained for the premodulation processor and the VHF/AM transmitter-receiver.

3. The remaining equipment should be repackaged to increase unit reliability and decrease weight volume.

Subsequent to this analysis, in-flight maintenance and spares were eliminated from the design concept.

Block I and II Configuration Analyses

Various analyses have been completed for several proposed design changes; i. e., the modification of the mission success definition to reflect an increase in the importance of telemetry data and the deletion of in-flight

[redacted]

maintenance. The reliability logic diagrams were updated and utilized in analyses to determine the effect on spacecraft reliability. It was concluded that redundancy would be required in the PCM telemetry equipment and in the signal conditioning equipment in addition to the S-band redundancy to achieve the reliability objectives. Implementation of these suggested redundancies is under study.

Redundancy Trade-Off Study (S-Band Power Amplifier Versus Premodulation Processor)

A reliability trade-off study indicates that the premodulation processor power supply and voice discriminator should be made redundant in the Block II configuration in lieu of the S-band power amplifier. The relative increase in reliability per unit of added weight would be larger by a factor of 1.5.

Coordination Meeting

A reliability coordination meeting was held with the subcontractor. At this meeting, it was agreed to improve the failure reporting system and submit identification and traceability exemption requests for the data storage equipment. The parts approval program was reviewed, and action was taken on all requests for deviation.

Program Review

A program review of the communications and data subsystem was held at Collins Radio Company in May to determine the status of the design, test, reliability, and manufacturing effort. The specific reliability tasks discussed were the failure reporting system, the parts approval program, the material selection effort, the mission life test program, the failure effects analysis effort, the part application test program, and the parameter variation analysis effort.

TEST PROGRAM

Qualification temperature test profiles were revised to reflect latest test criteria. This will reduce over-all test time and subject the equipment to the mission simulated sequence and temperature extremes for re-entry and early recovery phases.

Prequalification testing (development testing) on engineering models (E models) is 95 percent complete. The environmental testing of E models is performed to the same levels as required for formal qualification of D models to assure that the equipment will pass the formal qualification requirements. A redesign effort is required on some equipment due to unacceptable resonances during vibration and the inability to pass the humidity environment test.

PLANNED ACTIVITIES

Reliability analysis will be continued to optimize the Block II communications and data subsystem configuration and to contribute to the ability of the present C & D subsystem configuration to accomplish the mission objectives of the early airframes. Technical surveillance of the subcontractor's reliability effort will continue to assure full consideration of reliability during the design and manufacture of the C & D subsystem.

GUIDANCE AND NAVIGATION

SUMMARY

Several significant analyses and report reviews were conducted. These analyses are briefly discussed in the following paragraphs.

ANALYSIS

Failure Mode and Failure Effects Analysis

A review was conducted of the failure mode and failure effect analyses of Apollo guidance equipment performed by MIT/IL. Comments are withheld pending further coordination to determine the impact on the failure mode and failure effect analysis caused by the removal of spares and maintenance as a requirement for the G&N subsystem.

NAA/S&ID—MIT/IL Interface Control Specification

An outline was completed for updated reliability requirements for SID 62-1000, Apollo G&N Performance and Interface Requirements Specification. Reliability and environmental requirements are being updated to reflect the most recent data.

Spacecraft Rendezvous Radar/Transponder Requirements

The environmental criteria for the spacecraft rendezvous radar/transponder were updated. Combinations of the longest duration burning times for the SPS and RCS motors were evaluated for the purpose of determining worst-case thermal environments for the spacecraft rendezvous radar antenna in the passive and in the operating mode. Results of these studies are shown in Tables 2-1, 2-2, and 2-3. Table 2-1 shows the approximate burning time of the SPS and RCS motors during the retro into lunar orbit phase. This phase of operation is considered to represent worst-case conditions of the rendezvous radar antenna in the passive mode. Table 2-2 gives approximate burning times and sequences of combined SPS and RCS firings in the CSM retrieval of the LEM phase of operation. Significant events include the insertion from circular orbit into the LEM retrieval transfer trajectory, LEM rendezvous midcourse corrections, and terminal rendezvous corrections. Table 2-3 shows maximum estimated burning times for the RCS motors in the terminal docking phase of operation. Worst-case thermal environment for the rendezvous radar antenna has been determined to be the delta velocity corrections greater than 10 feet per second with all quads operating in the minus x direction for 25 seconds in the terminal docking phase of operations.

Rendezvous Radar/Transponder Performance and Interface Requirements Specification

Reliability inputs were submitted for inclusion in the NAA/S&ID-GAEC preliminary specification for rendezvous radar/transponder performance and interface. Requirements for reliability design, equipment availability under flight conditions, and service life were established.

TEST PROGRAM

Test program activities included a review of MIT G&N Test Plan R434, the inclusion of test inputs to the outline of SID 62-1000, Apollo G&N Performance and Interface Requirements Specification, and Support of the SID briefing to NASA at Downey, which presented G&N equipment reliabilities.

The test program support of the LEM consisted of the establishment of the environmental test criteria for the rendezvous radar system, the writing of the preliminary performance and interface specification, which included the qualification test levels for the rendezvous radar system, and the briefing preparation for NASA, MIT, and GAEC on NAA/S&ID's environmental requirements for the rendezvous radar system.

Table 2-1. Retro Into Lunar Orbit

	Approximate Burning Time In Seconds		
	RCS Motors		
Flight Event	B_3	C_3	SPS Motor
Lunar orbit acquisition orientation	3	3	
Propellant settling maneuver	5	5	
Lunar orbit injection maximum			565
Total	8	8	565

Note: Maximum burning time combinations and sequences of RCS and SPS motors for (antenna not operating) maximum thermal stress determination

Table 2-2. CSM Retrieval of LEM

Time of Event $T_O = O$*	Flight Event	Approximate Burning Time in Seconds			
		RCS Motors		SPS Motor	
		B_3	C_3	Upper Limit*	Nominal
T_O	CSM transfer to retrieval orbit				
	Thrust vector orientation	3	3		
	Propellant settling maneuver	8	8		
	ΔV firing			12.5	6.02
T_O + 20 minutes	First midcourse correction				
	Thrust vector orientation	3	3		
	Propellant settling maneuver	8	8		
	ΔV firing			2.5	0.80
T_O + 30 minutes	Second midcourse correction				
	Thrust vector orientation	3	3		
	Propellant settling maneuver	8	8		
	ΔV firing			1.5	0.51
T_O + 45 minutes	Third midcourse correction				
	Thrust vector orientation	3	3		
	Propellant settling maneuver	8	8		
	ΔV firing			1.0	0
T_O + 50 minutes	First terminal rendezvous correction				
	Thrust vector orientation	3	3		
	Propellant settling maneuver	8	8		
	ΔV firing			15.0	10.25

Table 2-2. CSM Retrieval of LEM (Cont)

Time of Event $T_O = O$*	Flight Event	Approximate Burning Time in Seconds			
		RCS Motors		SPS Motor	
		B_3	C_3	Upper Limit*	Nominal
T_O + 55 minutes	Second terminal rendezvous correction				
	Thrust vector orientation	3	3		
	Propellant settling maneuver	8	8		
	ΔV firing			5.0	4.0
T_O + 58 minutes					

*Upper limit firings are based upon a total budget of 22.75 seconds or 455 fps ΔV. Maximum duration firing of any one correction point precludes the likelihood for maximum duration firing at another.

Note: Approximate maximum burning time combinations and sequences of RCS and SPS motors for (antenna operating) maximum thermal stress determination

Table 2-3. Docking

Flight Event	Approximate Burning Time in Seconds			
	RCS Motors			
	B_3	C_3	D_3	A_3
ΔV correction greater than 10 feet per second, all quads operating	25	25	25	25
ΔV correction greater than 10 feet per second, one quad out—either	50		50	
—or		50		50

Note: Maximum burning time and combinations of RCS motors for (antenna operating) maximum thermal stress determination

PLANNED ACTIVITIES

Planned activities consist of submitting inputs for the NAA/S&ID G&N plan, coordinating with MIT to draw a G&N system model specification, obtaining information of the impact of the Block II configuration on the G&N test program, revising and updating the performance and interface specification for the rendezvous radar system, and evaluating information on the LEM reliability interface.

INSTRUMENTATION

ANALYSIS

Television Equipment

Revised procurement specifications from the supplier for camera parts have been reviewed and found satisfactory with the exception of the lens specification, which will require further revision.

The detailed reliability analysis reflecting the conversion from micro-modules to integrated electronic circuits in the camera was completed by the supplier. The basic assumption was made that the catastrophic failure of any single part will cause failure of the television camera to perform its function. The predicted reliability of the camera is 0.99901 for 40 hours of operation compared to the design goal of 0.999.

The application suitability of the Hughes connector for the television camera was investigated. Because a coaxial version of the Hughes connector is not available, the Deutsch DS connector was designated for use on the camera in place of the Hughes connector. A specification will be written by the supplier for procurement of the connector, modifying MIL-C-26484, as required, to be consistent with Apollo requirements.

A problem mentioned previously regarding the camera lenses has been alleviated. The supplier has subcontracted a development effort to qualify the lenses to the Apollo environments. Results are expected during the next quarter.

The final S&ID design review was conducted for camera electronics that employ integrated circuit packaging techniques. A change resulting from this review was the decision to operate the integrated circuits of the sync generator with a single positive-polarity power supply, rather than a positive and negative supply. This change will simplify and reduce power consumption and improve low-temperature performance.

Central Timing Equipment

Part specifications have been completed by the supplier for qualification and production models. The specifications have been evaluated and approved.

Several failures occurred during acceptance tests of the E2 model (to be used on Boilerplate 14) at the supplier's facility. Preliminary analysis indicated three basic causes for the failures. These causes were workmanship, design inadequacy, and faulty integrated circuits. Broken wires and poor welds apparently resulted from hurried construction and extremely tight mechanical packaging. The packaging has been redesigned for nonredundant time accumulators, and wiring layouts have been changed for the E3 model and subsequent models.

S&ID and Air Force quality control representatives now monitor the supplier's in-process inspection on a 100-percent basis.

A single design problem was isolated, and corrective action was taken. A buffer amplifier was added in the advance-retard circuitry to eliminate a transient spike produced by the advance monostable multivibrator. No other design problems, other than some possible packaging changes, are evident.

Integrated circuit failures were encountered after several hours of operation. These units were bought off-the-shelf for early central timing equipment (CTE) models. After purchase of these units, the CTE supplier generated procurement specifications for integrated circuits, which were approved by S&ID. Seventeen hundred of the commercial units were subjected to the specification screening and acceptance test, resulting in a yield of approximately 40 percent. Future circuits (for qualification and production CTE models) will be welded seal units, a more reliable packaging method than the commercial solder sealing, and must conform to the S&ID-approved specification. These controls should preclude, as practicable, failure of integrated circuits in future CTE models.

Disposition of the failures was as follows:

1. The broken wires were repaired.

2. An integrated circuit in the 10-pps frequency divider was replaced.

3. A buffer amplifier was added to eliminate the transient problem.

4. Failed integrated circuits in the time accumulator section will not be repaired. Attempted repair could result in additional damage because of inaccessibility within a large potted module. These failures only eliminate the operational redundancy in the time accumulator. Each functional output is operating; therefore, it is felt that the unit is satisfactory for use in Boilerplate 14. The reliability goal for the time accumulator output has been changed to 0.999 in the latest specification revision. The change resulted

from the reduced criticality of that function; i.e., the time accumulator output is used for time-coding of telemetry and photographic information.

Digital Up-Data Link

All part specifications received from the supplier have been evaluated, and comments have been sent to the supplier. Minor modifications on several specifications are required for complete acceptance.

As previously reported, electrical design is 100 percent complete, but some repackaging design is required because of the soldering specification, MSC-158A. The circuit design was accomplished with a worst-case technique requiring that the circuits meet any operating condition with all pertinent parameters and parts simultaneously at their worst possible values.

The supplier's identification and traceability plan and exempt parts list were reviewed and accepted.

Work should be completed on the failure mode and effects analysis, the reliability prediction, and the stress analyses early in the next reporting period.

Displays and Controls

Reviews were completed of identification and traceability plans for the hermetically sealed toggle switches and potentiometer, electrical meters, and the event indicators. The exempt parts list for the electrical meters was reviewed. Nonstandard and electronic parts lists were reviewed for the mechanical clock and timers as well as for the event indicators. Specifications for the caution and warning system and the entry monitor system were finalized.

Measurement Systems

Supplier electronic part specifications, nonstandard parts lists, and sampling plans have been reviewed and approved for the operational pressure and temperature transducers. Identification and traceability plans were reviewed for these units, as well as for the temperature measurement system.

General Instrumentation Specification

During this quarter, NASA requested S&ID to provide data regarding qualification and acceptance testing of Government-furnished boilerplate instrumentation equipment. These data include test requirements, anticipated environments, critical dates, test data content, and failure-reporting requirements. S&ID documented these data in a general instrumentation specification. Advance copies were presented to NASA in Houston. The final draft is intended for use by NASA and S&ID as a basis for qualification and acceptance testing of commercial and Government-furnished instrumentation equipment.

End Item Vehicle

The status of the instrumentation for Boilerplate 12, 13, and 15 and preliminary information on instrumentation for subsequent vehicles have been continually maintained. This effort includes review and analysis of the instrumentation equipment, comparison of qualification test criteria with the criteria anticipated for the affected vehicles, and recommendations for corrective action when discrepancies are noted. Records of tests performed on each instrumentation component are maintained for future reference.

TEST PROGRAM

Television Equipment

Acceptance and qualification test procedures for the television camera have been evaluated by S&ID, and the supplier was notified of the discrepancies. The development test program is presently scheduled to begin in August 1964, and qualification testing is scheduled to begin in November 1964.

Central Timing Equipment

Acceptance tests of model E2 were completed as previously discussed. Development tests on the prototype central timing equipment are being conducted. All subassembly tests have been successfully passed. The final assembly has passed high-low temperature and sinusoidal vibration tests. The unit passed electromagnetic interference susceptibility testing but failed radiated and conducted interference testing. Redesign efforts are in progress to correct these discrepancies, and the tests are to be re-run. The remaining development tests have been delayed because of the test specification negotiation between the central timing equipment supplier and the test facility. The testing is scheduled to resume early in the next quarter.

Digital Up-Data Link

The E model acceptance test procedures have been reviewed and approved, with minor changes. Acceptance tests were successfully completed on the E1 model, and it is presently in-house for use on Boilerplate 14. Design verification tests are being conducted on the E2 model, which will then be used in acceptance testing of the up-data link bench maintenance equipment.

Displays and Controls

Qualification and acceptance test procedures were reviewed for event indicators, electrical meters, the barometric pressure indicator, event timers, the clock, the toggle switch, and the potentiometer.

Measurement Systems

Qualification tests of the Q-ball were completed in time for Boilerplate 12 firing at WSMR. Phase C (static-firing) qualification tests were completed for the pressure and temperature transducers. Phase B (suborbital flight) qualification tests are in progress for these units.

Acceptance test procedures have been reviewed for the acoustic measurement system, stress measurement system, Q-ball, and pressure, temperature and mass flow transducers.

STABILIZATION AND CONTROL

SUMMARY

Reviews were performed in the areas of failure reporting and corrective action, end-item data packages, identification and traceability, and part procurement.

ANALYSIS

The input to the procurement specification for the director and response tester (DART) was completed. A reliability goal of 0.999 was apportioned to the equipment. The DART is to be utilized for unmanned flights and will automate certain functions normally performed manually. The primary function performed by the DART is providing backup capability to the G&N computer. A failure mode and effect analysis was conducted on the DART to determine the areas requiring redundancy to prevent spacecraft loss in the event of a failure. The preliminary estimate of reliability utilizing a 72-hour mission for the total spacecraft with DART resulted in 0.833 and 0.964 for a comparable manned flight. The manned flight has the advantage of being able to utilize spares where the DART flight does not. Additional redundancy was recommended to strengthen the DART type mission which would increase the estimated reliability to 0.887.

SUBCONTRACTOR MANAGEMENT

The stabilization and control subsystem end item data packages for mission simulator 1, mission simulator 2, and evaluator 2 were reviewed for reliability content. Every data package was found to be deficient in content. Areas of deficiency were:

1. No final corrective actions were taken on test discrepancies.
2. Engineering orders changing the end item drawings were not incorporated.
3. Corrected acceptance test procedures were not incorporated.
4. Replacement records were incorrect.

The subcontractor has been directed to correct these deficiencies.

TEST PROGRAM

Environmental and acceptance testing has continued on the following systems.

Functional Model A

High-low temperature tests have been successfully completed on the attitude set-gimbal position display, attitude gyro accelerometer package, electronic control assembly-auxiliary, rate gyro package, delta velocity display, electronic control assembly-roll, and electronic control assembly-yaw. Vacuum and acceleration, altitude, and post-vacuum tests have been successfully completed on the attitude set-gimbal position display, control panel, and delta velocity display, respectively. The attitude set-gimbal position display and control panel are presently undergoing humidity testing.

Development Model 1

Acceptance testing has been completed on all units, except the electronic control assembly-auxiliary.

Development Model 2

Acceptance tests have been completed on the control panel, electronic control assembly-rate, electronic control assembly-yaw, and electronic control assembly-pitch. The rate gyro package and attitude set-gimbal position display are presently undergoing acceptance testing.

System Verification Testing Model

Acceptance testing has been completed on all units, except the attitude set-gimbal position display, electronic control assembly-auxiliary, translation control, and rotational control. Acceptance tests are presently being conducted on the attitude set-gimbal position display, electronic control assembly-auxiliary, and translation control. Every data package was found to be deficient in content. Areas of deficiency are the following: No final corrective actions were taken on test discrepancies; engineering orders changing the end item drawing were not incorporated; and replacement records were incorrect. The subcontractor has been directed to correct these deficiencies.

PLANNED ACTIVITIES

Technical support to cost negotiations on the subcontractor's delta cost proposal will continue during the next quarter. Reliability support will be given to the Block II stabilization and control subsystem configuration. Subcontractor management will be continued to ensure proper compliance in areas such as failure reporting, corrective action, equipment buy-offs, finalized life test requirements, and end item data packages. Environmental and acceptance testing will be continued.

III. MECHANICAL SUBSYSTEM ANALYSIS

COMMAND MODULE HEAT SHIELD

Tests are being conducted to determine the best methods for qualification testing. Tests have shown that Chromalox strip heaters, rather than quartz lamps, will be the most effective means of heat generation for vacuum high-temperature testing. Avcoat 5026-39HC-G scrap panels will be subjected to vacuum exposure to determine the operational capability of the vacuum chamber when the materials outgas. Qualification test procedures for the heat shield ablative panels, abort, tower wells, special test samples, and the identification and traceability plan are being reviewed.

Additional progress relative to implementation of the qualification test program includes the final design of the main ablator test panels, design of test fixtures, design of the test set-up for the temperature-gradient and high-temperature vibration tests of the main ablator panels, and detail drawings of the combination hot/cold plate for the special test samples.

The development test program is approximately 90 percent complete. Qualification testing is scheduled to begin about 1 September 1964.

COMMAND MODULE REACTION CONTROL

ANALYSIS

An analysis of rocket engine valve failure detection was completed, including possible engine valve failure modes and their effects. Any failure mode of any engine valve which is not detected and isolated could result in crew loss.

The monitoring concept is basically a comparator-isolator logic function which would continuously compare command signals from the stabilization control subsystem with response signals from rocket engine valve piston position monitors. Whenever the response signal failed to match the command signal, an automatic isolation signal would be transmitted to the affected engine and/or subsystem module. Both apportioned and predicted numeric probabilities for each failure mode were included. These indicated total apportioned engine valve failures in excess of 1900 per million missions and total predicted engine valve failures in excess of 3700 per million missions. The complete apportioned command module RCS requirement is less than 40 failures per million missions.

RELIABILITY STUDY

A reliability study concerning mass equivalents of command module RCS toxicological tolerance limits was completed. This study was undertaken to determine the equivalent mass of the command module RCS propellant concentrations which have been established as emergency toxic tolerance limits when those concentrations are present in the command module volume with a three-man crew. The emergency limits were believed to be those beyond which the functional capability of the crew would be impaired. The final report of this toxic study described method, procedure, and results. Therefore, it is a convenient adjunct to the resulting maximum allowable spillage study. This new study determined mass equivalents of lethal toxic concentrations of man for short command module exposures. The amount of reactant spillage which results in death once in 10,000 five-minute exposures (total subsystem requirement is less than 0.4 crew loss per 10,000 missions) is 4.18 grams of MMH or 1.28 grams of N_2O_4. After a normal mission with no system failures and a successful purge, there are expected to be 740 grams of MMH and 1360 grams of N_2O_4 remaining at impact.

TEST PROGRAM

Continued development efforts are being accomplished to effect a noncracking throat insert which is capable of any mission duty cycle without performance degradation. Presently available materials are not suitable for both pulse-mode and/or long-duration steady-state firing.

Significant reliability growth has been accomplished by redesign of the helium fill/drain disconnect coupling compression poppet seal which resulted in compliance with all design requirements testing during the development phase.

PLANNED ACTIVITIES

The following are activities to be accomplished:

1. Investigation of explosive effects which could be caused as six different active liquid reactants are supplied to the vehicle on the launch pad.

2. Investigation of potential environmental control system/command module reaction control system interface hazards.

CREW PROVISIONS

SUMMARY

Waste management system component development and design verification testing is being completed and qualification testing will have begun on all waste management components by July 1964. Test hardware and testing requirements for in-house fabricated hardware were established. Review of the spacesuit assembly interim qualification tests for suits used on the environmental control system breadboard test was completed.

TEST PROGRAM

Backup Valve

The formal qualification test report of the backup valve was reviewed and approved. Qualified hardware has been approved for shipment.

Waste Management Control Unit

The waste management control units failed to pass the leakage test during qualification after being subjected to the fluid compatibility test. This resulted in a redesign of the poppet and seat to improve the point contact pressure and the restart of the qualification tests. The failure was traced to an excess amount of deposits and to corrosion on the valve seat. The redesign of the poppet seat included a knife-edge construction which gave a wiping action as the poppet closed onto the seat, and a Teflon lining of the internal parts of the valve. The supplier performed a fluid compatibility and functional test of the redesigned valve as a rerun of development testing prior to starting the new qualification tests to ensure that the recommendations were effective. Rework of the failed units is not acceptable for the new qualification test program or for delivery.

Ventilating Check Valve

The supplier of the ventilating check valve reported that by using improved tooling and revising the technique used in cutting and sealing the corners of the lip seal of the internal rubber flapper, the valve has passed the internal leakage test. Manufacture of the qualification test hardware is complete and has passed the required acceptance tests. Qualification is expected to be completed next quarter.

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Bacteria Control Unit and Urine Disposal Lock

Fabrication of the qualification test hardware of the bacteria control unit and the urine disposal lock has been delayed pending procurement of the rubber bladders. Prequalified hardware have utilized seamed bladders which are inherently not as reliable as the one-piece bladders planned for all qualified hardware. The one-piece bladder molds and molding process have been finalized and no further delays are anticipated. Qualification testing of both units are scheduled to start in mid-July.

Vacuum Cleaner and Blower

Fabrication of the qualification hardware and phasing out of the design verification tests are proceeding on schedule for the vacuum cleaner and blower. The qualification and acceptance test procedures for both units were approved. A summary of the component test status on the waste management system is shown in Table 3-1.

Table 3-1. Waste Management System Component Test Status

Component	Development (% Complete)	Design Verification Test (% Complete)	Qualification or Start Date (% Complete)
Backup valve	100	100	100
Waste management control unit	100	90	20 (To be rerun)
Ventilating check valve	100	100	30
Bacteria control unit	100	100	July 1964
Urine disposal lock	100	100	July 1964
Vacuum cleaner	100	70	June 1964
Blower	100	80	June 1964

Test Hardware Requirements

Qualification test hardware requirements were established for in-house fabricated hardware and system tests. Each item was reviewed and, based on its criticality, test hardware requirements were established. The functional and environmental requirement were established. The general and formal test requirements will be included in the process specifications that are to be generated.

Space Suit

Review and recommendations of proposed interim qualification tests for space suits to be used on the ECS breadboard tests were completed.

CRYOGENIC STORAGE

SUMMARY

The major analysis effort was devoted to the proposed Block II configuration. A study was performed for evaluation of system changes for Block II weight reduction of a one-tank configuration as opposed to the present two-tank configuration. The comments concerning Block II in this report refer to this system change. Required activities on the cryogenic storage system included performance of failure modes and effects analyses, logic diagrams, and special studies.

Reliability activities also included surveillance of subcontractor failure reports, follow-up of design review action items, review of the end item acceptance test data package, participation in the subcontractors' cost-reduction program, and review of the subcontractors identification and traceability procedures.

ANALYSIS

Cryogenic Storage System Block II Changes Analyses

Several single-point failure modes of a catastrophic category are associated with the single-tank configuration. They are tank burst and any excessive leakage which would deplete the system fluid before service module separation, either during normal mission or in an abort condition. Possible leak sources are plumbing fittings, relief valve, fuel cell valve module, and any disconnect closure.

Although these failures could affect crew safety, if lower-limit AVCO failure rates are employed, the probability of occurrence of any of these is sufficiently low, and total design reliability remains at a level consistent with present reliability goals.

Further refinement of the Block II configuration was recommended to include the following design features.

1. Reduction of critical line fittings. This may be accomplished by manifolding the fuel cell valve modules to the tank valve modules, or an integrated unit at the tank.

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2. Separate supply lines to each fuel cell incorporating flow restrictions and isolation capabilities at the valve module end of the lines.

3. Addition of flow restrictions and isolation capabilities in the main ECS oxygen supply line at the valve module ends, and the necessary strength requirements to facilitate this addition.

4. Incorporation of a standby capability for ECS oxygen supply line with an alternate line for the case of high flow demand for command module pressurization or backup for leaks developed in the primary line.

Reliability Studies

Three electrical configurations were proposed for the Block II design. An analysis was performed to determine the system possessing the highest predicted reliability.

1. Present Configuration: A pressure switch to automatically operate the tank heater and manual override capability.

2. Solid-State Configuration: A solid-state switching circuit for each phase of the fan motors and for each manual heater circuit. The solid-state switches are operated on a signal from a pressure transducer.

3. Solid-State Switch: A solid-state switch to drive a relay which then controls the heater circuit. The solid-state switch is operated by a signal from a pressure transducer. A manual override is provided in this design.

In systems 2 and 3, employing solid-state switches, reliability is affected by the need for pressure transducer activation. Since pressure transducers are low-reliability components, it was not recommended that they be incorporated in controlling circuits of the series configuration. The "pressure switch" configuration does not depend on the transducer, except in a complete automatic circuit failure when the pressure gauge must be employed by the crew to maintain proper fluid pressure. The pressure gauge operates on a transducer signal. It was recommended that the pressure switch configuration be maintained, with the incorporation of a separate circuit breaker for the solenoid valve and the heater. A single circuit breaker in any of the proposed systems decreases reliability by decreasing standby and redundant modes of operation. Also, a failure of a single circuit breaker would result in a double failure at one point in the system. In addition, the power supply for the manual and automatic circuits should not be provided by the same bus.

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TEST PROGRAM

Pressure Vessels

1. Three production titanium pressure vessels have successfully completed the prequalification tests.

2. The AFRM 006 oxygen tank successfully passed the vibration portion of the end item acceptance test while loaded with inert test fluid.

3. The first titanium preproduction qualification pressure vessel fractured during burst testing at 1419 psi and a cryogenic temperature of -420 F. The minimum burst pressure for this vessel is 450 psi.

4. Five hydrogen production pressure vessels have passed acceptance tests and are now undergoing final assembly.

5. Heat leak tests have been completed on hydrogen engineering and oxygen engineering models. No performance change was experienced after the models were subjected to the design proof vibration test and the heat leak requirements were met.

6. The titanium prequalification test vessel fractured at 812 psi while at 79 F during the burst pressure test. This vessel had previously been subjected to the 330-hour creep test and 50 proof pressure cycles without any evidence of permanent deformation. All test results exceeded test objectives.

Shipping Container

Two shipping containers, one oxygen and one hydrogen, were subjected to end-item acceptance testing, but both failed the leakage test. A third oxygen shipping container was successfully subjected to end-item acceptance testing.

Disconnects

Seven oxygen disconnects were subjected to the end-item acceptance test. Only five passed; the failed units exceeded the specified leakage rate.

Signal Conditioners

Three out of 23 signal conditioners failed the end-item acceptance tests. Two units were out of tolerance by a small margin, and the third failed the insulation resistance test.

Fan Motor

During the development program on the fan heater motor, the problem of end-plate galling, tearing, and pitting while being subjected to vibration was resolved by the replacement of the aluminum shims with stainless steel shims and the redesign of impeller hub from a pin type to a welded type.

Valve Module

One oxygen fuel cell valve module successfully completed the end-item acceptance test. One hydrogen fuel cell valve module failed during the leakage test.

PLANNED ACTIVITIES

S&ID will continue to assess test data received from suppliers and monitor test program activity. The failures previously mentioned will be investigated, with a final evaluation of each to be completed during the next quarter.

EARTH LANDING

SUMMARY

Corrective action to eliminate earth landing system component failures has resulted in modifications of the baroswitches and reefing cutters. The Boilerplate 6 inertia switch failure has resulted in a detailed study of impact load criteria. Reliability has investigated the Boilerpate 12 failures and is satisfied that adequate corrective measures have been taken.

ANALYSIS

Baroswitches

During this reporting period, the earth landing system (ELS) baroswitches were modified to increase the opening-closing pressure differential (deadband) from 2 to 5.5 inches of mercury. These switches are actuated by atmospheric pressure, which deflects a belleville spring. The spring, in turn, contacts a microswitch. During vibration tests, several of the 2-inch deadband switches failed to close when the test unit was returned to atmospheric pressure. Analysis revealed that: (1) the adjustment of the electrical microswitch assembly was not in the center of the narrow tolerance band and (2) the vibration environment prevented the belleville spring from overcoming the physical resistance of the microswitch. These switches, however, functioned normally during post-vibration tests. It was concluded that the 2-inch deadband design did not provide the belleville spring with sufficient force and travel to operate during vibration. This malfunction was corrected by modifying the switches to incorporate a 5.5-inch deadband.

Boilerplate 12 Parachute Failures

Analysis of the Boilerplate 12 mission films have revealed the following: One parachute was lost when the riser bent the dummy reaction control system installation and became entangled under the drogue-riser guide. The riser was severed by the exposed edges of the drogue disconnect, allowing that parachute to drift away. Analysis revealed that Boilerplate 23 and other recoverable vehicles use stronger structural members to prevent the main risers from entering the bulkhead area under the drogue riser guide; therefore, this particular failure mode should not occur on future flight tests.

One of the remaining two parachutes split from crown to skirt band during disreef. Calculations indicate that the parachute should have withstood the dynamic pressure. It is suspected that the parachute was weak at the point of failure initiation due to the lack of continuous tapes. A similar failure at El Centro revealed a stitching fault at the point where segmented tapes were sewn together. Final analysis of this failure is pending investigation of the parachutes by S&ID. All future flight vehicles will use parachutes with continuous tapes. This design should reduce considerably the chance of a similar failure occurrence.

Boilerplate 6 Inertia Switch Failure

An investigation has been made to determine the cause of an apparent inertia switch failure on Boilerplate 6. Although there was no main parachute disconnect on this boilerplate, each inertia switch output channel was monitored by telemetry. Upon impact, a signal was received only from one channel. Examination of the impact acceleration trace revealed that the impact g load was within the region where the switch may operate, but this is not required. (The impact switch specification defines three regions on a graph of g load versus time. The switch must not operate in Region I, may or may not operate in Region II, and must operate in Region III.) It was concluded that the 25-g setting used on Boilerplate 6 is slightly beyond the impact load envelope. At this time, a study is in progress to determine the tolerances required for proper inertia switch operation. Drop test data are being used for this study.

Two-Parachute System Reliability Study

The possibility of using only two main parachutes in the earth landing system to reduce weight was studied. In order to eliminate a single-point failure, this system would require single-parachute capability. Investigation revealed that the present shock attenuation system would allow crew emergency limits to be exceeded during single-parachute landing conditions. For this reason, it is recommended that the present three-parachute configuration be maintained.

Earth Landing System Logic Diagram

Figure 3-1 is the logic diagram depicting the sequence of events during operation of the ELS.

TEST PROGRAM

Laboratory

The new pilot and drogue mortar fixtures which simulate airframe structure have been used successfully. The mortars are being modified to accomodate the small pilot and drogue chutes.

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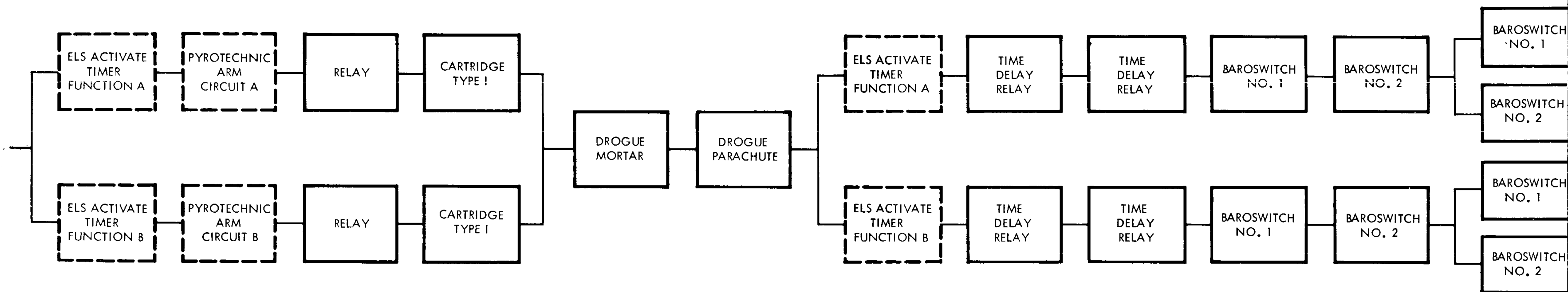
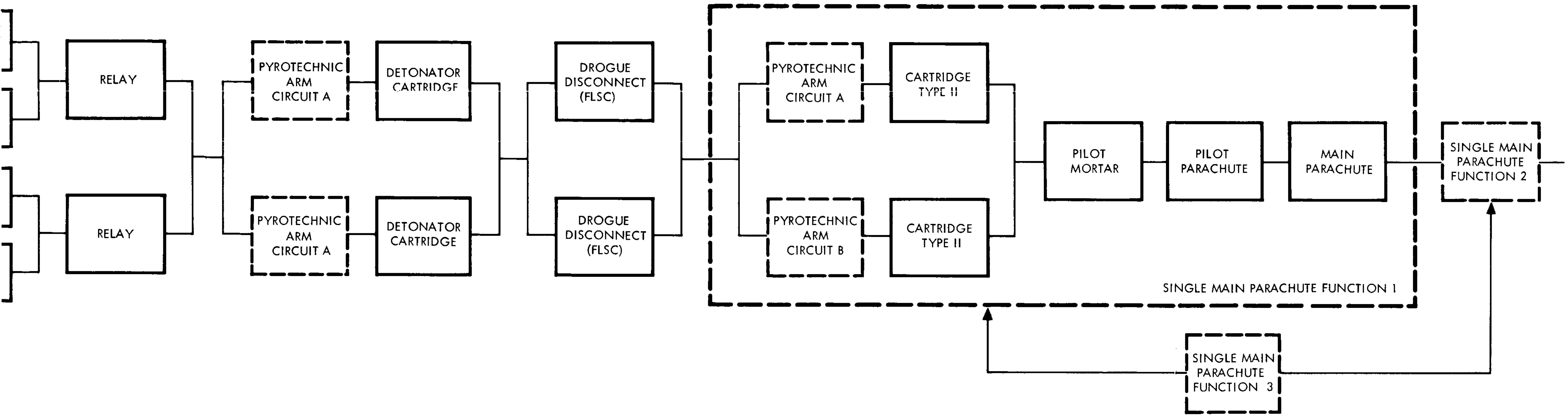


FOLD-OUT #1



FOLD-OUT #2

Figure 3-1. Earth Landing System

The firing pin spring of the reefing line cutter does not have enough force to overcome and fire an opposing steady-state acceleration of 600 g's. The spring force has been increased by 2.75 in an effort to meet the specification requirement of firing while exposed to an opposing acceleration of 1000 g's.

Steel risers for the drogue and pilot chutes have been designed and manufactured. Deployment characteristics of the steel risers are being evaluated.

Abrasion resistance and ultimate-load tests are being conducted on parts of the drogue, pilot, and main chutes and associated harnesses.

Flight Tests

Drop tests 50 through 61 have been performed to evaluate various main parachute configurations such as removal of various percentages of the fifth ring, various percentages of reefing, removal of four gores, and various suspension line lengths. Based on the above tests, the following was learned or verified.

1. Approximately 11-percent mid-gore reefing improved inflation.
2. Removal of approximately 75 percent of the material from the fifth ring improves the main chute inflation, reduces opening load, and reduces oscillations.
3. A suspension line length of 120 feet has proved to be optimum for rate-of-descent considerations.
4. Removal of gores increases the rate of descent. Further testing is required.

Drop test Boilerplate 19-12 was for direct support of Boilerplate 12 high-altitude abort test. All test objectives were met.

PLANNED ACTIVITIES

Manufacture of parachutes for support of the drop test program will continue.

Reefing-line-cutter development will continue, mortar firings of the pilot and drogue chutes will be conducted, and temperature-vacuum testing of parachute textile samples will continue.

ELECTRICAL POWER

ANALYSIS

Electrical Power System Weight Reduction Study

A study was conducted to determine the effects on reliability of the proposed Block II changes for the electrical power system. The proposed changes analyzed were:

Item 1. Eliminate one of three fuel cells and associated hardware.

Item 2. Eliminate one of three inverters and associated hardware.

Item 3. Eliminate one of two a-c buses.

Item 4. Eliminate one of two d-c buses.

Item 5. Eliminate present inverters and associated hardware and replace with two redundant inverter/battery-charger units.

Item 6. Eliminate post-landing battery and use LEM battery for post-landing power.

Item 7. Repackage reentry and post-landing batteries.

Item 8. Eliminate two pyrotechnic batteries by using reentry batteries for pyrotechnic power.

Item 9. Eliminate two service module RCS sequencer-logic-power batteries (pyrotype) by using fuel-cell power.

Analysis results of the above items are summarized in Table 3-2. Component and subsystem reliabilities were computed from predicted failure-rate data and represent the most accurate estimate to date.

Fuel Cells

Analytical studies which consider eliminating one of the three fuel-cell modules were conducted in support of the proposed Block II configuration. Elimination of a single fuel cell would result in a weight reduction of approximately 400 pounds. The present fuel-cell subsystem consists of three

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Table 3-2. Electrical Power Analysis Results

Reference Item No.	Component Failure Rate	Present Subsystem Reliability MS	Present Subsystem Reliability CS	Proposed Subsystem Reliability MS	Proposed Subsystem Reliability CS	Remarks
		Failures per 10^6 Missions		Failures per 10^6 Missions		
1	$16.378(10^{-5})$	480	60	4,970	1,520	In the two-fuel-cell subsystem an abort now occurs when one fuel cell fails, whereas in the three-fuel-cell subsystem two fuel cells are allowed to fail.
2	$12.2754(10^{-5})$	270	26	18,718	876	In the two-inverter subsystem an abort now occurs when one inverter fails, whereas in the three-inverter subsystem two inverters are allowed to fail.
3	$0.00325(10^{-5})$	5	Less than 0.1	8	8	Although the mission success reliability is not affected appreciably, the removal of one a-c bus injects a single-point failure mode into the electrical power system. Also, the switching from one a-c bus to another for emergency power during midcourse correction has been eliminated. This is a mandatory condition which must be satisfied in order to preclude loss of SCS single bus or inverter failure occurs.
4	$0.01038(10^{-5})$	16	Less than 0.1	26	26	Although the mission success reliability is not affected appreciably, removal of one d-c bus injects a single-point failure mode into the electrical power system.
5	$14.275(10^{-5})$	27	26	21,782	1,184	The battery charger is now a critical item because of the elimination of one battery.
6	$0.8(10^{-5})$	7	7	3,198	3,198	The proposed subsystem MS and CS reliability is based on worst-case conditions (i.e., the LEM not returning from the mission).
7						Reliability analysis not available due to lack of design information. However, no serious degradation in mission reliability is expected unless repackaging results in smaller total watt-hour capacity.
8						Use of a common supply for both logic and pyro power is against all basic design safety regulations. This change would affect mission reliability associated with all sequencer operations. Time constraints for this study and the complex reliability logic required prevent determining the reliability numerics associated with this change. However, if this change were implemented, the following present basic ground rules would be violated: 1. NASA directive that all pyro and logic circuits be electrically isolated. 2. Independent logic and pyro arm and checkout. 3. Two independent electrically isolated logic sources.
9						Total evaluation of this change is not now available; however, preliminary evidence indicates that a definite increase in unreliability could be expected. This expected increase in unreliability appears to be approximately 260 failures/10^6 missions. (Present≈10 failures/10^6 missions, proposed ≈275 failures/10^6 missions.)

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fuel-cell modules connected in parallel with each module and capable of providing an emergency power of 2195 watts.

The existing and projected failure-rate data used in the analyses were independently derived by the subcontractor and S&ID. The subcontractor's values were based on a continual advancement in state-of-the-art fuel-cell technology (i.e., achieving an extended electrode life of 1000 hours, compared to the present 400 hours). The failure-rates were obtained by projecting the present 400-hour fuel-cell reliability numeric on a 1000-hour-life scale and utilizing Weibull-plot data.

The S&ID approach modified the generic failure-rate data to reflect the reliability progress during the present development program. The diagram in Figure 3-2 illustrates the basic difference between the two- and three-module systems. It also indicates that, although the resulting reliability for a single module exceeds the apportioned reliability of 0.971, there is a considerable degradation in the mission success profile. It should be noted that both subcontractor and S&ID predictions, when referenced to crew safety, meet the basic apportioned requirements.

Inverter

The latest reliability prediction has been delayed by the supplier because of a design change to correct excessive electromagnetic interference generated by the inverter. Preliminary analysis indicates that the interference is caused by transients from a fast switching transistor and unshielded terminals. The supplier proposes to add additional circuitry and to shield the terminals as a means of eliminating these transients.

The supplier has been informed that Specification MIL-R-27542 will be replaced by S&ID's Reliability Program Specification MC999-0067. The new specification contains the normal reliability requirements for prediction, failure-mode and effects analysis, logic diagrams, failure reports, etc., and requires the supplier to use the S&ID high-reliability preferred-parts manual. The latter requirement will save time by eliminating duplicate electronic-component procurement specifications and test and failure-rate information. Receiving inspection time may be reduced because the high-reliability components are inspected at the vendors by S&ID. Parts ordered with the above controls require full traceability.

Battery Charger

The battery-charger high-reliability program is on schedule. Effort has been directed by S&ID toward review and approval of specifications used to procure high-reliability electronic components.

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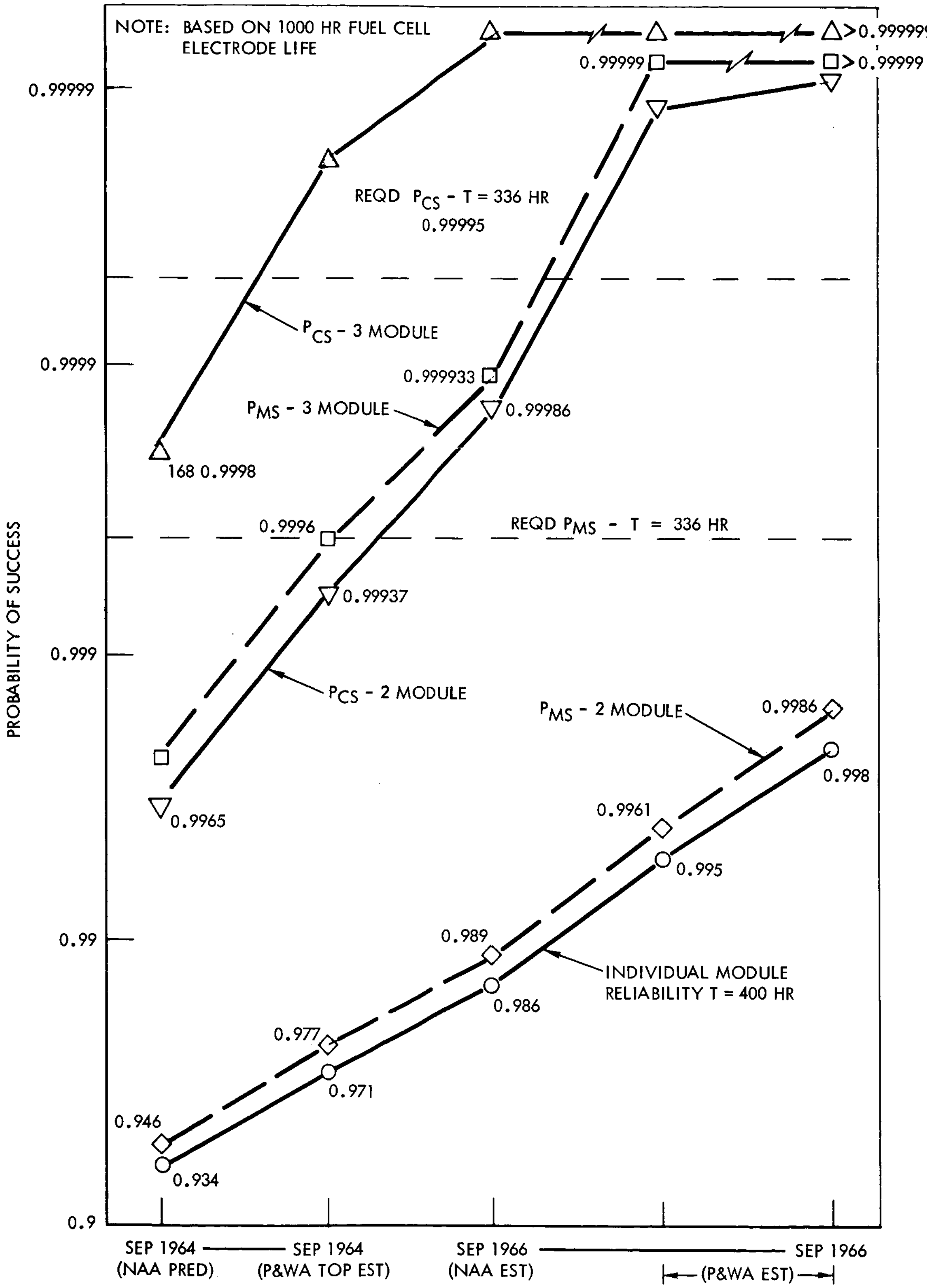

Figure 3-2. Projected Fuel Cell Reliability Growth

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A study was conducted to determine the criticality ranking of the battery charger because of increased loading on the reentry batteries. Results indicate that redundant battery chargers are not necessary, if the loading on the batteries does not increase. The battery subsystem is designed to supply 2100 watt-hours. The total watt-hours required from the battery subsystem currently is 2369 watt-hours. Considering that the battery charger is a high-reliability component (0.995) and that entry can be effected even if the battery charger has failed (assuming two fuel cells are operating), redundancy is not recommended at this time. However, a light-weight redundant battery charger for Block II is being considered. The battery-charger supplier indicates that a redundant battery charger can be developed which would be more reliable and weigh less than the present battery charger.

Power Distribution

Technical evaluation meetings were held in April with two potential suppliers to determine whether these companies are capable of implementing reliability programs to support the production of circuit breakers purchased to S&ID control drawings. Because the subject control drawings apply at this time to hardware which does not require qualification for the specific application, the potential suppliers were approved for limited procurement. Additional surveys will be required prior to consideration for approval as a source for man-rated, spacecraft hardware.

Mission Sequencer

During the minimum airworthiness tests (MAT) associated with Boilerplates 12 and 13, a number of nonconformance reports (NCR's) were written. Most of them indicated the necessity for, and resulted in, immediate corrective action in manufacturing processes and handling. Most of the problems are explained below.

Two 15.5-second time-delay relays in Channel "B" of the Boilerplate 12 mission sequencer failed. These failures were detected during random vibration in the "Y" axis, when the tower jettison command was initiated at 9.3 seconds instead of the required 15.5±0.5 seconds. Analyses indicated the cause to be timer sensitivity to undervoltage transients. Testing revealed that an early time-out of as much as 10 seconds could result from the following conditions: (1) voltage drops from a normal 28.0 dc to 18.0 dc, 10.0 dc, or 0.0 dc with pulse widths of 10 to 1000 microseconds and repetition rates of 2 to 400 cps. The data resulting from these tests were reviewed and analyzed by S&ID and the relay supplier. A filter network was developed which reduced the transient sensitivity to an acceptable level. All Boilerplate 12 time-delay relays were returned to the supplier and modified.

Two motor-driven switches exhibited excessive transfer times in the Boilerplate 13 mission sequencer. The out-of-tolerance condition occurred during a functional test after the sequencer box had been subjected to a high-temperature environment of +140 F for 24 hours. Analysis performed on seven additional motor switches revealed that excessive transfer time is inherent in the particular motor switch being used. The most probable cause is the high-temperature bonding of the brake mechanism. Investigation produced the following information: (1) The failure occurs only on the first ambient operation following a high-temperature soak, and (2) operations following the failure will be normal (i.e., transfer time of less than the specified limit of 120 milliseconds). To prevent recurrence of this condition it has been recommended that all motor switches be cycled 25 times at +150 F, with functional tests being performed at room temperature before and after the 25 cycles and with the recorded transfer times to agree within ±20 milliseconds. Note that excessive transfer time would cause no detrimental effect on the functional operation of the Boilerplate 13 mission sequencer, but if continuous, could ultimately cause the motor to burn out.

The boilerplate mission sequencer failed to verify a logic A safe condition of a functional test after random vibration in the X axis. Troubleshooting of the sequencer revealed a broken base lead on a transistor. This transistor was removed for additional failure analysis. Microscopic, metallurgical, and chemical analysis showed evidence of poor workmanship and plating discrepancies in the lead which failed. Material discrepancies also were found in all leads. Several precautions will contribute to failure-recurrence prevention, among which are (1) a more conscientious application of the intent of the stress-relief provisions for mounting configurations, (2) elimination of "free-standing" leads on future units, and (3) where the latter is not practical, the use of adequate potting material. This last provision was implemented as corrective action for Boilerplate 15, 16, and 26.

TEST PROGRAM

Fuel Cells

Development powerplant X406-4 has successfully completed 468 hours under load during a vacuum endurance test.

A PC3A-2 powerplant was subjected to acceleration, vibration, and 12 starts. Acceleration and vibration was accomplished with no malfunctions. During the fourth start cycle, before vibration, two cells developed bubbles, and the performance dropped below the specification requirements. These cells were replaced and no variations in performance resulted during or as a result of the vibration. During the sixth start cycle, four cells demonstrated low performance. Tear down revealed that seven cells had developed bubbles and were replaced. The glycol pump, the nitrogen fill valve, the hydrogen purge valve, and the oxygen purge valve were replaced after malfunctions. The powerplant was subjected to four additional starts for a total of ten. On the 11th cycle a hydrogen leak developed which was corrected by tightening a fitting on the line to the hydrogen manifold. Cycle 12 was completed satisfactorily, and the powerplant was started on a new simulated qualification sequence in humidity. After ten days in humidity, the powerplant operational parameters were within specification limits.

The bubbles which occurred in nine cells during the test sequence described above were attributed to a lack of scinter integrity, not to the environments to which the powerplant was subjected. The subcontractor has a program to upgrade scinter integrity.

Two additional PC3A-2 powerplants are scheduled for acceleration, vibration, starts, and vacuum-endurance in a design verification test series during the next quarter. These powerplants will resemble closely the bill of materials for the qualification units.

Results of the first tests performed at S&ID on three fuel cells include information on purging and parallel powerplant operation. One unit was tested for its capability to meet the purge requirement. This unit accumulated 100 hours under load in three starts and demonstrated that the powerplant purge capability is 3 to 4 times greater than originally required. Tests were conducted on the other two fuel cells, and they showed that, when the cells are placed on load individually and then placed onto a common load, they will provide stable operation.

Formal qualification testing is scheduled to begin 1 October 1964.

S&ID Engineering Development Laboratory has three powerplants awaiting completion of a vacuum chamber that will hold all three simultaneously. These powerplants will be subjected to system testing during the next quarter.

Three prototype "B" powerplants have been delivered to S&ID for use on Boilerplate 14.

Connectors

Qualification of the general-purpose spacecraft connectors, PV type, began on 25 May 1964, and is scheduled for completion the last week of July. No problems have been encountered to date.

Minor problems occurred during qualification testing of the DPK rectangular connectors. Previous problems with high-mating forces and material cracking at low temperatures have been corrected. Completion of qualification is scheduled for the first week of July.

Problems with the hermetic sealing process and with contact resistance have occurred during qualification of the command module bulkhead-feedthrough connectors. The contact material has been changed. Both problems are now under control, and qualification will begin in early June and is scheduled for completion by the first week of August.

The unsealed model of the subminiature connector for the crew compartment has completed development testing. Several changes are necessary prior to initiation of qualification. The sealed version presently is being subjected to development tests.

Qualification will begin next quarter for the launch-escape-tower umbilical, the forward-compartment umbilical, the GSE-to-spacecraft umbilical, and the special-application connector.

Inverter

Two design-verification units are undergoing extensive supplier in-house evaluation tests. These units will not be shipped to S&ID. Two prototype units are in acceptance test, and six others either are awaiting acceptance tests or are completing the manufacturing cycle. The eight prototype units are to be shipped to S&ID for boilerplate end-item application and engineering-evaluation tests. Currently, the supplier is experiencing difficulty with unbalanced power stages and an out-of-tolerance EMI. A design change to provide for ripple feedback in the oscillator stage during synchronization is expected to correct the balance problem.

Qualification tests currently scheduled to start in September 1964 probably will be rescheduled because of the above problems.

Battery Charger

Four prequalification units have been delivered to S&ID. Two units will be installed in house spacecrafts No. 1 and No. 2. The other two are for engineering-evaluation tests.

The qualification prototype unit currently is undergoing electrical proof-testing and will be subjected to environmental proof tests in June 1964. This prototype will provide proof-test history for the qualification production units. The prototype and production units are electrically equivalent, but the prototype unit does not use high-reliability components.

Start of qualification tests has been rescheduled for August 1964. This reschedule is necessary to provide sufficient lead time for the procurement of high-reliability components.

Pyrotechnic Batteries

Six units have been scheduled for development tests at the supplier's facility. The first unit has completed the tests and the second is in development test. Four units are still in fabrication. Results of development tests to date has shown the need to improve performance characteristics and to correct sealing deficiencies within the cells.

Qualification testing of the pyrotechnic batteries is scheduled to start in August 1964.

Storage Batteries

Two prequalification units have been received by S&ID for engineering-evaluation tests. The cells for the qualification-test units are ready for installation into the battery case, and qualification tests are scheduled to start the latter part of August 1964.

Motor Switches

Power Transfer Switch (ME 452-0036)

The development stage is complete. Qualification tests are scheduled to start in June 1964.

Power Overcurrent Switch (ME 452-0038)

A redesign of the sensing portion was necessary to protect the fuel cells during warm-up. The new configuration will provide a one-megohm minimum load to the fuel cells during warm-up. The redesign is complete, and production of the qualification-test units will start in September 1964.

RCS Transfer Switch (ME 452-0044)

The qualification test units were rejected by the Air Force inspector because of noncompliance with the NASA soldering specification. It appears that unless NASA waives this rejection, new units will have to be built. Qualification tests have not been rescheduled to date.

Overcurrent Relay Switch (ME 452-0055)

Development tests will be completed early in the next quarter. Qualification tests will start in September 1964. No significant problems have been encountered.

ENVIRONMENTAL CONTROL

SUMMARY

Major reliability effort on the environmental control system during the report period consisted of analytical support to design engineering for Block II changes. These changes are being proposed to reduce spacecraft launch weight, to improve system operation, and to increase reliability of the ECS.

Two reliability studies were conducted on the water-glycol evaporator control system and on proposed vapor vent duct heater configurations. The present water-glycol evaporator control system is deficient from a crew safety standpoint because of numerous single-point failures. The ECS vapor vent duct outlet freezes closed during water boiling conditions.

Other activities included design review, minimum airworthiness requirements for boilerplate vehicles, processing of nonconformance reports resulting from boilerplate cooling tests, surveillance of subcontractors test programs, and review of the end-item acceptance data package.

ANALYSIS

Redundant Coldplates and Addition of Third Pump (Block II)

The water-glycol coldplate circuit configuration used to cool the command module electronic modules is being considered for redesign to provide redundant cooling capabilities for critical flight safety electronic modules. This redesign will provide crew safety capabilities for a safe abort not present in the current design in the event of a major water-glycol leak. To further increase safe abort capability and extend mission capability of the water-glycol circuit, a third water-glycol pump is being considered for incorporation into the system. These changes are shown in Figure 3-3.

The effects of these proposed design changes upon the overall ECS mission success and crew safety reliability goals are shown in Table 3-3.

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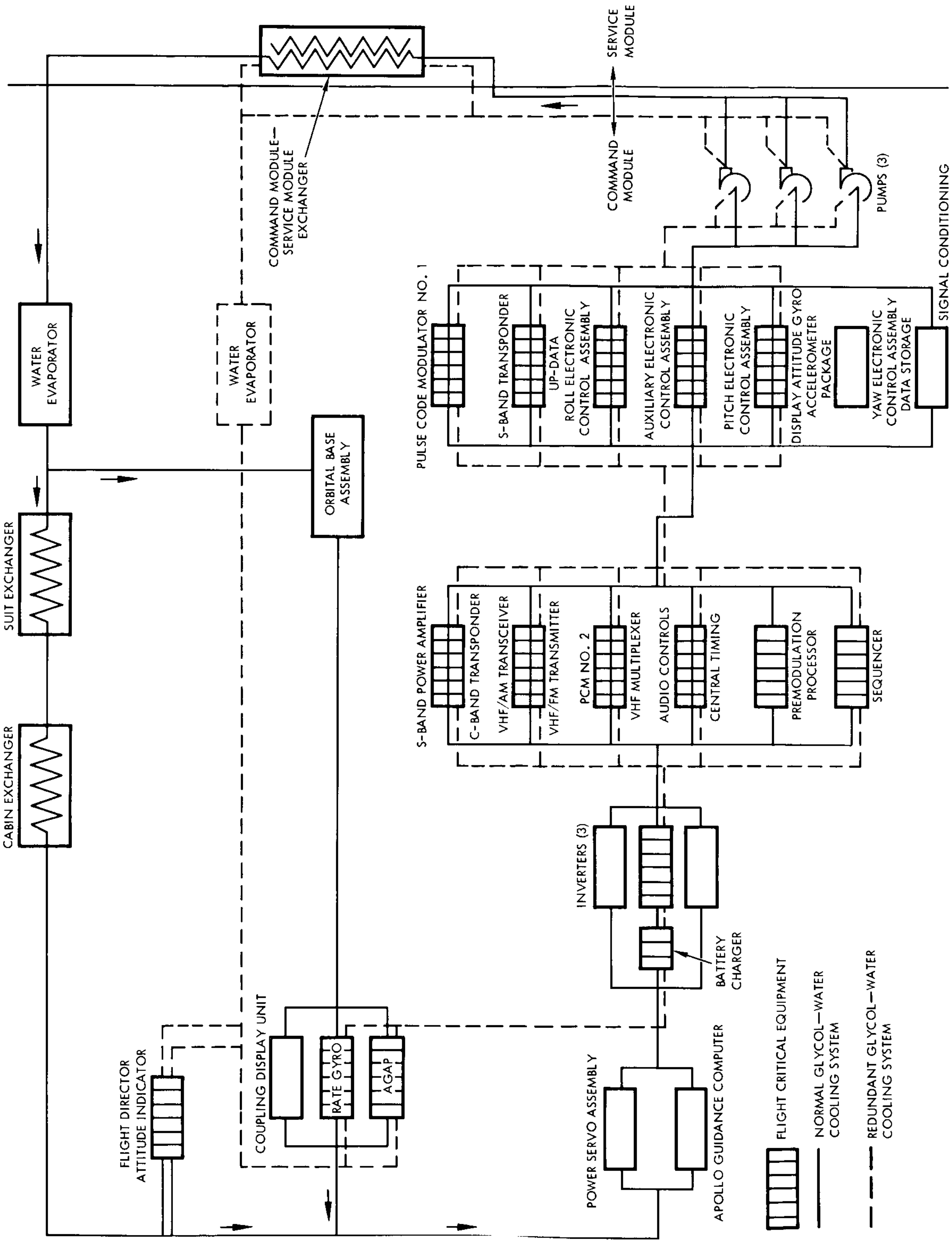

Figure 3-3. Block II Command Module Glycol-Water Cooling System

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Table 3-3. Comparison of Present and Proposed ECS Configuration Reliability Values

Configuration	Mission Success Reliability		Crew Safety Reliability	
	Apportioned	Predicted	Apportioned	Predicted
Present ECS Single coldplate loop and two pumps	0.9935	0.9870	0.9997	0.99962
Proposed Block II ECS Redundant cold-plates of critical components and three pumps	0.9935	0.9935	0.9997	0.9998

Service Module Freon Cooling System (Block II)

The present ECS requires the use of water boiling evaporators and space radiators to control the temperature of the water-glycol heat transport medium. A Block II design change is being proposed that will replace the present service module water-glycol loop with a separate Freon system. The Freon system shown in Figure 3-4 has the following advantages over the water-glycol loop:

1. Eliminates a potential water-glycol freezing problem in the space radiators
2. Reduces the criticality of the water-glycol evaporator control system by permitting complete temperature control of the water-glycol required for inertial measurement unit operation
3. Use of water for boiling to provide additional cooling is reduced, thereby allowing larger reserve for transfer to lunar excursion module.

In addition, the service module Freon system could be expanded to include heat transfer capabilities for the fuel cells and critical areas of the service propulsion system and reaction control systems.

The predicted reliability values for the proposed service module Freon system of Figure 3-4 are shown in Table 3-4.

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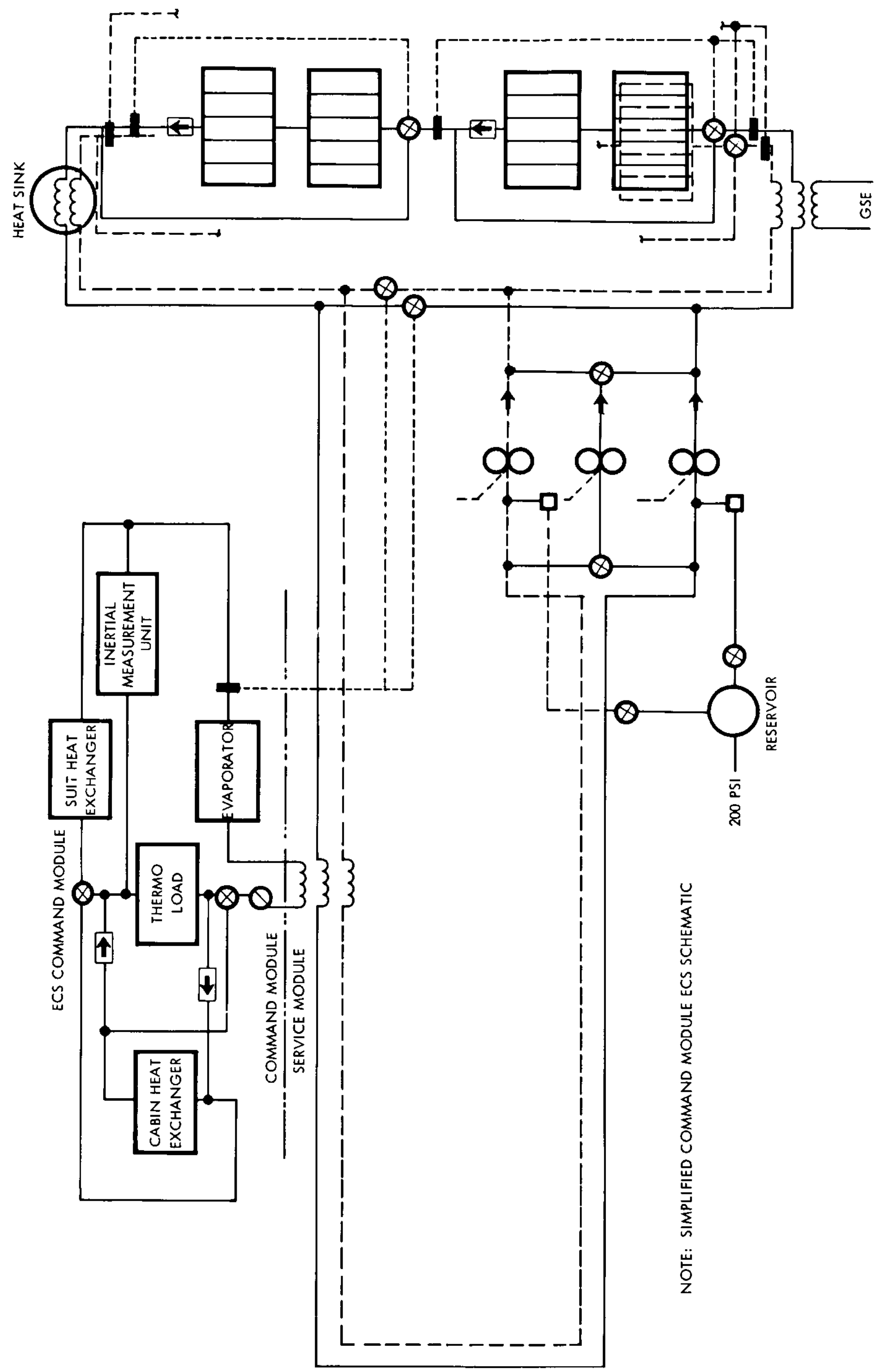

Figure 3-4. Service Module Secondary ECS Loop Plus LEM Water (TCS Passive)

Table 3-4. Proposed Service Module Freon Cooling System Reliability Values

Configuration	Mission Success		Crew Safety	
	Apportioned	Predicted	Apportioned	Predicted
Service module Freon system	0.9990	0.9962	0.9999	0.9999
With fuel cell heat transfer added	0.9990	0.9912	0.9999	0.9997

The predicted reliability values are based upon 147 hours for mission success and 189 hours for crew safety with abort being required after two Freon pumps have failed. The system was analyzed from a preliminary design concept only, and it is anticipated that the predicted reliability values will improve and approach the goals as design details are finalized.

Vapor Vent Duct Heater Analysis

Engineering tests on the ECS vapor vent duct indicated that a freezing condition during ECS evaporator boiling and urine expulsion would block the duct outlet at the surface of the spacecraft. A blocked duct would prevent (1) use of the waste management system, (2) water-glycol cooling at the evaporator, (3) water boiling at the suit evaporator, and (4) overboard discharge of the other associated system.

To prevent freezing, heaters will be required within the duct and at the outlet. Three design concepts were analyzed for their relative reliability merits. The first was four heating elements electrically in parallel, two for the duct and two for the outlet, which would operate continuously. The heating elements are sized so that one in each location would prevent freezing. The second was two heaters in series, one for each of the duct and outlet locations. They would operate continuously. The third is a standby system consisting of two heaters in series, continuously operating, and an identical circuit to be activated if the operating system fails. The results of the analysis are shown in Table 3-5. The standby system was recommended because it did not contain single-point failures.

Table 3-5. Proposed Vapor Vent Duct Heater Reliability Values

Configuration	Predicted Reliability
4 heaters (parallel system)	0.999863
2 heaters (series)	0.999858
Standby system	0.999999

Water-Glycol Evaporator Control System

A reliability analysis of the water-glycol evaporator control system was conducted because of the criticality of components in the system. Primary function of this system is to provide water-glycol at a temperature of 45±2 F to the inertial measurement unit (IMU). This temperature is critical for proper IMU operation and requires water boiling in the evaporator. Three major single-point failures were found during this analysis that would cause a mission abort because of the lack of adequate water boiling capabilities in the evaporator. These failures are:

1. Fail-open condition of the water supply valve to cause freezing in the back-pressure control valve or steam duct

2. Failure of the back-pressure control valve actuator, its control or sensors, and jamming of the valve

3. Failure of the wetness control and sensor to provide correct signal for the water supply valve.

The effects of the evaporator control system (back-pressure control and wetness control) on reliability of the water-glycol circuit as compared to a previous system without these control circuits are shown in Table 3-6.

Table 3-6. Water-Glycol Circuit Reliability With and Without Evaporator Control

Reliability Type	Without Evaporator Control	With Evaporator Control
Mission success	0.9967	0.9802
Crew safety	0.9998	0.9981

To improve the reliability of the water-glycol circuit the following recommendations were made:

1. Provide a bypass around the water supply valve for isolation, and allow an alternate path for water supply to the water-glycol evaporator.

2. Design the back-pressure valve to fail open or provide manual override capability that would allow the valve to be opened if the actuator failed.

These recommendations would require evaluation of the instrumentation available to detect critical failures and that required to correlate performance parameters of the various proposed manual controls.

TEST PROGRAM

A prototype temperature control unit has been tested for 6723 hours. This completes all of the development testing, but the life testing will continue to 10,000 hours for further evaluation. The unit met design requirements.

The suit supply pressure transducer failed to meet the EMI requirements. The unit was reworked, and met all EMI requirements when retested.

During assembly testing, the cabin temperature control and the back pressure control did not meet the dielectric strength test requirement. The insulation material used to isolate the welded module from the case exhibited reduced insulating characteristics under pressure. As a result, insulation breakdown occurred. Other insulation materials are being evaluated.

The cyclic accumulator selector successfully completed humidity testing, and the solenoid has undergone a 100, 000 operational cycle life test.

Humidity and temperature tests were completed successfully on the shutoff valve and the solenoid has been subjected to the 50, 000 operational cycle life test.

During water-glycol simulated loop tests with radiator pressure drop to investigate heating modes, the subsystem exhibited a relatively slow response to glycol temperature transients. The response was improved by increasing the valve speed. A pressure drop across the space radiators in excess of the 16-psi relief valve setting would cause a bypass of a major portion of the glycol flow, resulting in insufficient radiator cooling. This, in turn, would result in increased evaporation of water by the glycol evaporator. Performance tests were conducted on the oxygen flow transducer subsystem to determine the temperature range of the input gas to the transducer at ambient temperature of approximately 70 F.

Investigation revealed discrepancies both in the theoretically calculated available temperatures and in the calibration curves provided with the transducers. The units will be recalibrated and modifications to the specified inlet temperature parameters will have to be negotiated.

Development testing is approximately 88 percent complete. Of a total of 737 planned tests, 652 have been completed and 18 are in progress. All testing has been completed on development units. Tests in progress or planned are design verification tests on production-type units.

Qualification Tests

The following items have successfully passed the mission sequential tests portion of the qualification test program:

Glycol shutoff valve
Glycol check valve
Water shutoff valve
Radiator check valve
Cabin blower closure
Water check valve

Acceptance Tests

Three production-type coldplates were subjected to a development pressure drop test. Two units passed and the third unit was marginal. One unit was successfully subjected to the following dynamic tests: Leakage, proofpressure X-ray, acceleration, acoustics, shock, pressure cycling, vibration, and burst pressure tests. Another unit was subjected successfully to the operational thermal test.

ECS Radiators - Development Tests

One roll-bonded ECS radiator was subjected to the following development tests: Thermal, pressure drop, vibration acoustics, honeycomb bonding, proof pressure, burst pressure, and adapter strength tests. All tests were passed successfully except the thermal test. The passages on the four outer tubes did not allow a sufficient flow rate, causing a temperature drop. A viscosity drop and an increased heat loss resulted which in turn froze up the panel. The unit is in redesign to enlarge the passages to increase the flow rate.

Developments tests on the radiator coating has indicated that the Armour Research Foundation coating ARF 441-2 was the best material.

LAUNCH ESCAPE

SUMMARY

Development testing programs for the launch escape and pitch control motors have been completed. However, the development test program for the tower jettison motor has not been completed due to a change in the thrust vector angle requirement caused by addition of the boost protective cover for the command module. The qualification test program for the launch escape system will begin in June 1964. The qualification test procedures for motors of the launch escape system have been found to be acceptable. Test results from flights of Boilerplate 12 and Boilerplate 13 indicate acceptable performance of the motors.

ANALYSIS

A reliability assessment was performed based on predicted and established parameters of the launch escape motor. The assessment included calculation of the reliability value of the launch escape motor assuming Atlantic Missile Range atmospheric conditions and probability of passing the launch escape motor qualification program. The reliability value is 0.987 at 50-percent confidence, and 0.952 at 90-percent confidence. The probability of passing qualification is 0.983 at 50-percent confidence, and 0.927 at 90-percent confidence. The difference between the reliability value and probability of passing qualification is that grain temperature is fixed during qualification, while grain temperature at the Atlantic Missile Range is dependent upon local atmospheric conditions.

The following parameters were included in the assessment:

Condition	Analytical method
Catastrophic	
Probability of ignition	(Go-no-go data)
Probability of nonexplosion	(Chamber stress/strength data)

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Condition	Analytical method
Performance	
Thrust rise time probability	(Probability of conformance to specification requirements determined from performance variables data)
Thrust performance probability	
Thrust angle probability	
Total impulse probability	

Listed in Tables 3-7 and 3-8 are probabilities of the above conditions at the 50- and 90-percent confidence level.

A reliability assessment of pitch control motor performance variables has been completed. The assessment results indicate that no problem is anticipated during qualification.

Thirty-two pitch control motors were fired; 12 were high-impulse motors and 20 were low-impulse motors. The low-impulse motors will be used on Apollo vehicles. The demonstrated reliability of low-impulse motors is 0.966 at the 50-percent confidence level and 0.891 at the 90-percent confidence level.

The present demonstrated reliability of the tower jettison motor based on binomial sampling at the lower limit is 0.938 at 50-percent confidence and 0.863 at 90-percent confidence.

Structural analysis indicates that safety margins are being achieved on the structure associated with the launch escape subsystem.

TEST PROGRAM

A total of 26 launch escape and tower jettison motors and 28 pitch control motors are left for the qualification program. The ability to assess reliability was not thought to be seriously affected by deletion of the aforementioned motors from the test program.

The high temperature test requirement for firing the launch escape system motors was reduced from 140 to 120 F. This enhances reliability predictions since motors fixed at 140 F showed there was some probability that motors fired at 140 F would exceed the upper specification thrust limit, whereas a high probability exists that motors fired at 120 F will not exceed the upper specification thrust limit.

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Table 3-7. Reliability Value as a Function of Predicted Parameters

	Parameters	Limits	Reliability 50% Confidence Level	Reliability 90% Confidence Level
P_1	Probability of ignition	(Qualitative - cartridges only)	0.999977	0.99974
P_2	Probability of non-explosion	(Maximum pressure < 2450 psia)	$1-(1 \times 10^{-14})$	$1-(1 \times 10^{-10})$
P_3	Thrust rise time probability	(50 to 120 milliseconds)	0.99947	0.99178
P_{4a}	Average thrust probability	(147,250 pounds at 70 F and 36,000 feet)	0.9876	0.9610
P_{4b}	Minimum thrust probability	(121,000 pounds at sea level)	0.999926	0.999559
P_{4c}	Maximum thrust probability	(200,000 pounds at vacuum)	0.999990	0.999806
P_5	Thrust angle probability	(2-3/4±1/4 degrees or 150 to 180 minutes)	0.99999	0.99962
P_6	Total impulse probability	(515,000 pounds-second at sea level)	0.999972	0.99937

Table 3-8. Probability of Passing Qualification as a Function of Established Parameters

	Parameters	Limits	Probability 50% Confidence Level	Probability 90% Confidence Level
P_1	Probability of ignition	(Qualitative - cartridges only)	0.999977	0.99974
P_2	Probability of non-explosion	(Maximum pressure <2450 psia)	$1-(1 \times 10^{-14})$	$1-(1 \times 10^{-10})$
P_3	Thrust rise time probability	(50 to 120 milliseconds)	0.99947	0.99178
P_{4a}	Average thrust probability	(147,250 pounds at 70 F and 36,000 feet)	0.9876	0.9610
P_{4b}'	Minimum thrust probability	(at 20 F)	0.99139	0.96863
P_{4c}'	Maximum thrust probability	(at 120 F)	0.99665	0.98156
P_{4c}''	Maximum thrust probability	(at 130 F)	0.98870	0.96110
P_{4c}'''	Maximum thrust probability	(at 140 F)	0.97370	0.93500
P_5	Thrust angle probability	(2-3/4±1/4 degrees or 150 to 180 minutes)	0.99999	0.99962
P_6'	Total impulse probability	(at 20 F)	0.99932	0.9935

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A boost protective cover was added to the command module structure. This necessitated a nozzle redesign for thrust vector angle for the tower jettison motor. Five additional development motor firings will be required to prove this design change, with the first of these firings scheduled for early July 1964. Manufacturing modification of nozzle assemblies will be required for some motors already fabricated. Two simulated altitude firings have been requested to substantiate performance of the redesigned thrust vector angle under flight conditions.

The last five TE-381 pyrogen units for the tower jettison motor have been fired verifying the integrity of the modified pellet basket assembly.

To date, 27 tower jettison motors have been fired with one nozzle closure failure. As a result, a nozzle closure redesign was implemented to preclude additional nozzle closure failures.

The performance of the launch escape motors during the flights of Boilerplate 12 and Boilerplate 13 was apparently successful, although the Boilerplate 12 launch escape motor chamber pressure signal was lost, and thrust performance for the pitch control motor was approximately 5 percent below predicted value.

Exhaust plume impingement tests are currently being conducted utilizing batch test motors. The purpose of the test is to predict the effect of the exhaust plume from the launch escape motor on viewing ports of the command module. Test results are not yet available.

The qualification test program was reduced by two motors for each of the three launch escape system motors as a result of the cost reduction program. The motors eliminated were those associated with the temperature gradient test.

PLANNED ACTIVITIES

Qualification testing on launch escape system motors will commence during the coming quarter. Analysis of performance data from test firings, assessment of the launch escape and pitch control motor at completion of qualification, and assessment of the tower jettison motor at completion of development and qualification are planned for the next quarter.

SEPARATION SYSTEMS AND PYROTECHNIC DEVICES

SUMMARY

Prototype qualification tests were completed on the command module to service the module separation system. A special development test program was completed for the dual mode explosive bolts in the tower separation system, and development tests are under way on the forward heat shield separation system and CSM umbilical disconnect. The flights of Boilerplates 12 and 13 included successful operation of the tower separation system (single mode explosive bolts); command module to service module separation system; drogue chute disconnect (detonators and linear-shaped charge); parachute mortars (pressure cartridges); and launch escape, pitch control, and tower jettison motor ignition (igniter cartridges).

TEST PROGRAM

Lot acceptance test firings were conducted for initiators, ignitor cartridges, single-mode explosive bolts, interim detonators, tension-tie cutters for command, service module separation, and pressure cartridges for drogue and pilot parachute mortars. In support of Boilerplate 12, prototype qualification tests were successfully completed for the tension-tie cutter, interim detonator, and parachute mortar pressure cartridges. Table 3-9 summarizes the test status of all pyrotechnic devices and components or systems using these devices.

PLANNED ACTIVITIES

During the next report period, prototype qualification tests will be completed for the dual mode explosive bolt. Development test firings of the thruster cartridges for the forward heat shield separation system will be in progress. Qualification of the standard hot-wire initiator is scheduled to begin in August 1964, and qualification of devices, components, and systems using the initiator will begin in December 1964.

Table 3-9. Test Status of Pyrotechnic Devices to 5 June 1964

Pyrotechnic Device	Phases Completed				Used On
	Design	Devel Test	Proto Qual	Qual Test	
Standard hot-wire initiator	X	X	X		All BP and SC
Pressure cartridge, drogue mortar	X	X	X		BP-12 and subsequent
Pressure cartridge, pilot mortar	X	X	X		BP-12 and subsequent
Pressure cartridge, propellant valve	X				BP-22 and subsequent
Pressure cartridge, circuit interrupter					AFRM 009 and subsequent
Pressure cartridge, forward heat shield	X				BP-22 and subsequent
Pressure cartridge, parachute release					Block II
Igniter cartridge, Types I and II	X	X	X		BP-12, 13, and subsequent
Detonator cartridge, interim	X	X	X		BP-12, and BP-23
Detonator cartridge					AFRM 002 and subsequent
Booster cartridge, linear shaped charge					AFRM 002 and subsequent
Explosive bolt, single mode	X	X	X	NA*	BP-6, 12, 13, and 15 only
Explosive bolt, dual mode	X	X			BP-23 and subsequent
Flexible linear-shaped charge	X				AFRM 002 and subsequent
Shaped charge cartridge					AFRM 009 and subsequent
Component or System					
Forward heat shield separation	X				BP-22 and subsequent
Tower separation with (13)	X	X			BP-23 and subsequent
Command module to service module separation	X	X	X		BP-12 and subsequent
Umbilical disconnect, command module to service module	X	X			AFRM 002 and subsequent
SLA adapter separation	X				Block II
LEM-adapter separation					Block II
LEM-service module umbilical disconnect					Block II
LEM docking ring					Block II
LEM docking latches					Block II
Service module propellant dispersal system	X				AFRM 009 and subsequent

*NA Not applicable

SERVICE MODULE REACTION CONTROL

SUMMARY

Reliability effort during this reporting period was concerned mainly with subcontractor and supplier management. Special emphasis was devoted to the approval and procurement of nonstandard electrical parts for the propellant quantity gaging system.

Several tradeoff studies were also performed on proposed modification of the present service module RCS. The modifications were all of a weight reduction nature and would be for Block II vehicles.

A preliminary reliability study was completed on a new service module RCS subsystem called the service module temperature control subsystem (TCS). The study included the preparation of logic diagrams, an apportionment, and the establishment of the mission success and crew safety criteria.

ANALYSIS

Block II Weight Reduction Study

Three tradeoff studies were performed on modifications of the present service module RCS configuration. The modifications were all of a weight reduction nature and were intended for possible use on Block II vehicles. Two of the modifications used a single central propellant supply subsystem for all the engines. Both modifications were unacceptable from a reliability viewpoint due to the existence of a single point failure mode that would result in loss of crew.

In the third modification, four aft pointing RCS engines were added to the rear of the service module, which would receive propellant from the SPS tanks. By providing more alternate modes of engine operation, the amount of redundant propellant required in each quad may be reduced. Early weight estimates of this modification indicated that the added hardware weight due to the additional engines would be more than compensated for by the reduction in the amount of redundant propellant required. The reliability evaluation of this modification also revealed that there would be an increase in both mission success and crew safety.

Temperature Control

A new subsystem has been added to the service module RCS for Block I vehicles called the service module temperature control subsystem (TCS). This subsystem will maintain the temperature within propellant limitations. A reliability review of the proposed design was completed and logic diagrams were prepared as presented in Figure 3-5.

The reliability apportionments for the service module TCS are as follows:

System	Apportioned Reliability	
	Mission Success	Crew Safety
Service module-TCS	0.999980	0.999999

The mission success and crew safety critieria for the temperature control system has been established as follows:

1. Emergency return can be accomplished by spacecraft reorientation.

   This requires the service module TCS to be successful for translunar flight only; i.e., affecting mission success only.

2. Abort when two out of the four service module TCS quadrant loops remain operable.

   The service module RCS must have any two quadrants operating successfully throughout the flight for safe return. This allows the mission to continue when one quadrant loop has failed, one pump failed and the automatic heater control has failed (manual backup assumed).

These criteria are intended to apply to earth orbital missions and should also be considered for lunar flight.

TEST PROGRAM

Continuing efforts are being made to incorporate preventive solutions to potential problems that could affect component or system reliability.

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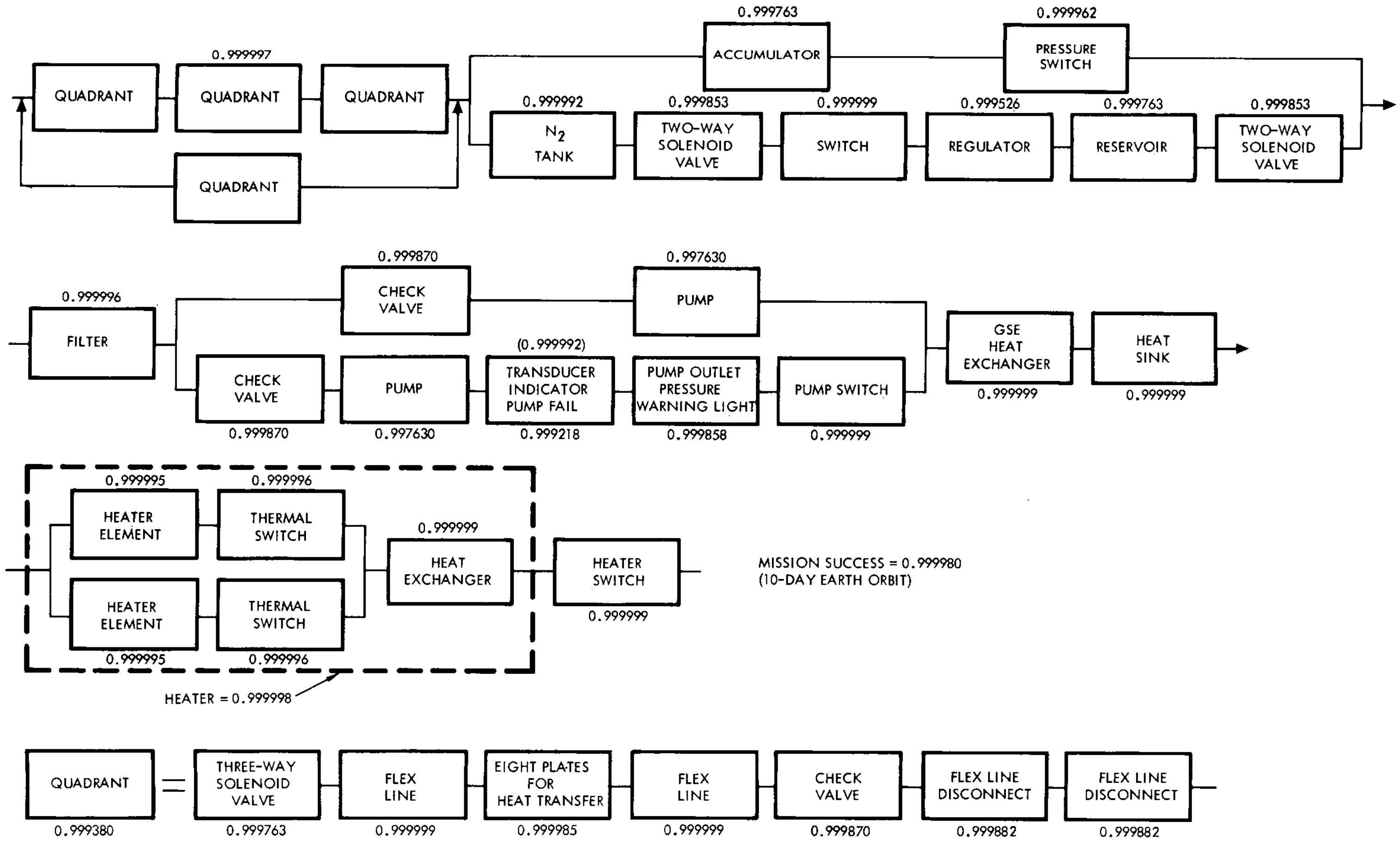

Figure 3-5. Service Module TCS Mission Success Logic Diagram

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Evidence of material displacement was noted in an injector used in the reaction engine. This material displacement was noted on the injector fuel hole exits and was affecting a partial restriction of the exits. This could cause major deviations in engine performance. Design review of injector configurations indicated the incorporation of a "V" groove between the fuel and oxidizer hole exits with the shortest possible free stream to impingement.

As the result of a design review effort, a propellant solenoid valve configuration was noted to possess a number of potential deleterious failure modes. Therefore, it was recommended by the reliability team and subsequently approved that design changes be incorporated to eliminate the potentially critical failure modes. Subsystem component hardware will be continually reviewed to acquire and validate the highest possible confidence level.

The service module reaction control system engine test failures accumulated through May 1964 are shown in Figure 3-6. There has been no change in the trend of failures since the last quarterly report. The search for design solutions for this explosion problem continues.

A major problem exists in the positive expulsion propellant assembly. The three-ply teflon bladder has continued to exhibit random ply separation due to propellant permeation with resulting creasing and subsequent failure. Exhaustive laboratory investigations are being conducted to solve the problem. Temperature effects on the bladder are also resulting in enbrittlement of the bladder causing fatigue failures. Investigations are being conducted to establish temperature effect parameters.

SUBCONTRACTOR MANAGEMENT

Reaction Control Engine

An S&ID audit of the reliability activities of the service module reaction control engine subcontractor revealed that, in general, the subcontractor's efforts were adequate. In the areas where the subcontractor's efforts or methods were found inadequate, S&ID is taking steps to correct the deficiencies through coordination meetings and the official transmittal of the findings of the audit.

The subcontractor has recently completed part of a special study dealing with the structural limitations of the combustion chamber. Marquardt report Apollo: Calculation of Minimum Material Ultimate Values Based on Tensile and Bending Test Data (R&PI; M/SA: 64-32; 20 March 1964) was reviewed.

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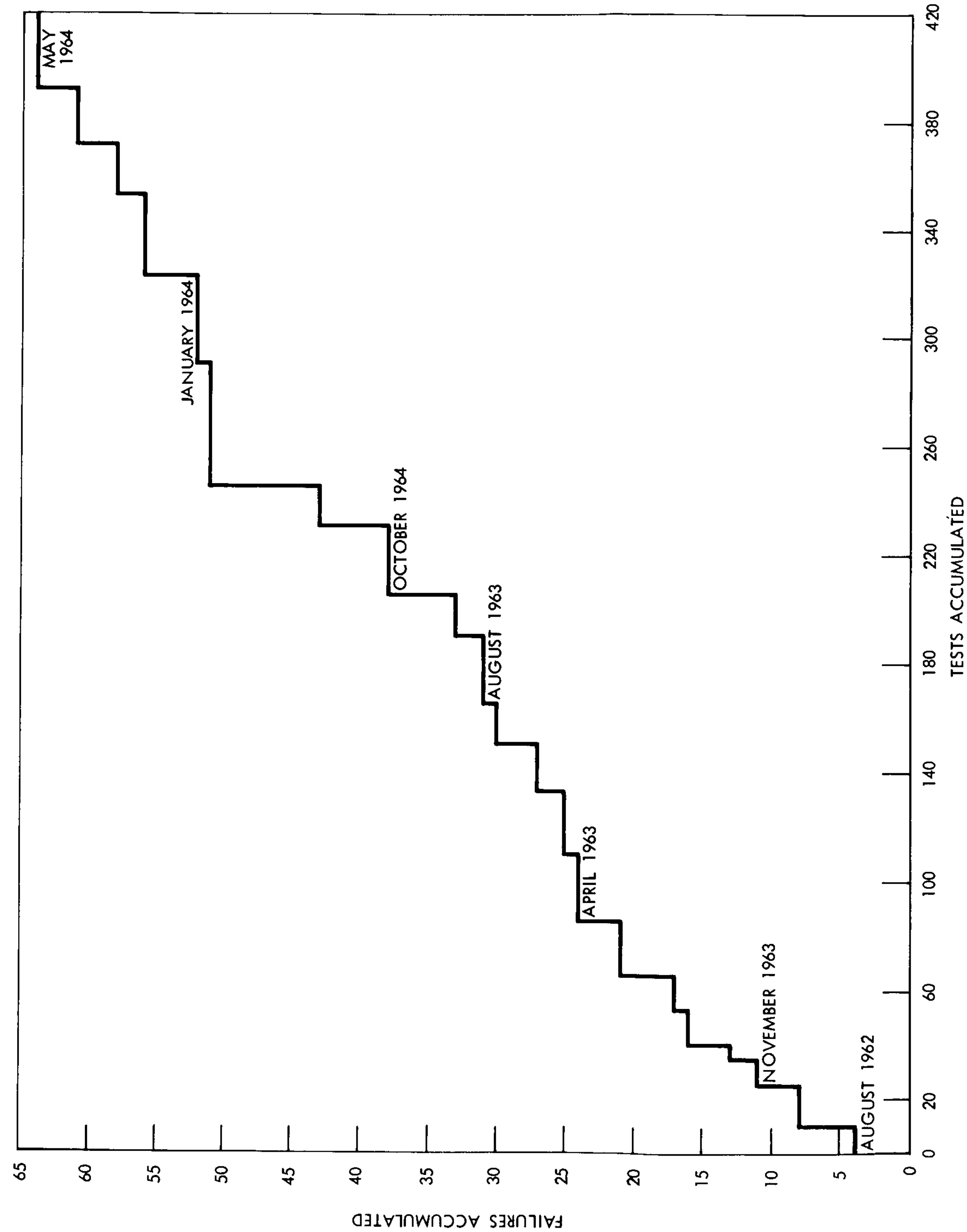

Figure 3-6. Service Module Reaction Control System Engine

The subcontractor also submitted for approval a configuration management plan and a sampling plan for the combustion chambers. Both documents were found to be inadequate and were returned for improvement.

Propellant Gauging

The primary area of activity both by S&ID and the propellant gauging system supplier has been in the preparation, review, and approval of nonstandard part specifications. Thirty-four nonstandard part specifications have been reviewed and approved by S&ID. Two more nonstandard part specifications have been submitted and are being reviewed.

Component procurement problems were encountered by the propellant gauging system supplier in an attempt to obtain satisfactory delivery dates for both nonstandard parts and S&ID hi-rel parts. The parts delivery problems were of prime concern to S&ID due to the possible serious delay to the propellant gauging system schedule to S&ID. To obtain satisfactory delivery dates for the needed parts, three major trips were made by a team of S&ID and supplier personnel to the manufacturers of the parts with the longest delivery times. The joint team approach was necessary to expedite technical agreement among S&ID, the gauging system supplier, and the parts supplier. A total of eight manufacturers were visited. In all cases, except one, the team was successful in obtaining satisfactory delivery by granting minor testing and I&T deviations. In that one case it was physically impossible to compress the production cycle enough to provide the needed parts on time.

An updated reliability analysis of the system was performed by the supplier utilizing proper derating technique. The analysis indicated that with a few minor changes, e.g., replacing a nonstandard part with a high-reliability part, the gauging system would approach its numerical reliability goal by the time of the first manned flight.

An I&T exempt parts list was prepared by the supplier and submitted to S&ID for approval. The document was reviewed, and the majority of the requested exemptions were granted. The list has been returned to the supplier with S&ID recommendations.

The duty cycle and the reliability allocation for the propellant gauging system have been revised. A reevaluation of the use of the system had revealed that the previous duty cycle was too stringent. The reevaluation indicated that the actual duty cycle would be approximately 37 hours instead of the previous estimate of 336 hours. An appropriate change in the numerical reliability goal of the system was also made. The purpose of modifying the reliability apportionment was to ensure that the new goal would be commensurate with the state-of-the-art increase required by the previous duty cycle and to provide for an equitable distribution of the required reliability improvement for the various service module RCS components.

PLANNED ACTIVITIES

The mission success and crew safety criteria for all of the instrumentation associated with the service module RCS will be reevaluated to determine the adequacy of the present ground rules. Particular attention will be given to the propellant quantity gauging system's mission success criteria.

The failure mode and effects analyses and logic diagrams for the service module reaction control system are being updated to reflect the addition of the temperature control subsystem and the change in the duty cycle for the propellant quantity gauging system.

A reliability audit of the propellant quantity gauging system supplier will be conducted during the next reporting period.

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SERVICE PROPULSION

SUMMARY

A revised subcontractor reliability program plan has been approved, and the tasks covered by the plan are being performed. The subcontractor monthly progress report for April 1964 containing updated failure mode and effects analyses, logic diagrams, apportionments, and assessments has been received. Thrust chamber assembly reliability based on hot-firing data is unchanged from that reported for the previous quarter (0.73 at 90-percent confidence limits or 0.81 at 50-percent confidence limits).

Subcontractor control of vendors is deficient, but component specifications are being definitized and reviewed by S&ID for compatibility with the procurement specification.

ANALYSIS

A special analysis was performed of the effect on gimbal actuator reliability if the actuators are used to hold the engine on centerline during boost. This added use may be required to avoid damaging the service module antennae by excursions of the SPS engine nozzle extension.

The study indicated that a considerable decrease in reliability would result from the proposed operation. The crew safety showed an increase of 816 failures per million missions, and mission success showed an increase of 7067 failures per million missions. These results were based on the following assumptions:

1. During 713 seconds of boost time, the SPS engine will experience oscillations at a frequency of 0.5 cycles per second; therefore, gimbal actuator cycle requirements are increased by 357.

2. The reliabilities of the individual gimbal actuator assemblies were considered to be in series relationship, since both actuators must work whenever the SPS is fired. For mission success, all components within each actuator were considered in series, since on failure of any one component, the mission would be aborted. For crew safety, the electrical harness, clutch, motor, velocity generator, and potentiometer were considered to be redundant. Reliability changes of individual components are shown in Table 3-10.

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Table 3-10. Reliability Changes of Individual Components

Component	Failure Rate	Operating Time (No Lock-In)	Operating Time (Lock-In)	Reliability (No Lock-In)	Reliability (Lock-In)	Change in Reliability
Harness and connectors	0.0001857/hr	0.2083 hr	0.3272 hr	0.9999613	0.9999392	0.000022
Dual clutch	0.0000025/c	209.5 c	566.5 c	0.999476	0.998584	0.000892
One d-c motor	0.00003/hr	0.2083 hr	0.3272 hr	0.999994	0.999990	0.000004
One velocity generator	0.0003217/hr	0.2083 hr	0.3272 hr	0.999933	0.999895	0.000038
One dual potentiometer	0.00000333/c	209.5 c	566.5 c	0.999302	0.998114	0.001188
Gear train	0.00000025/c	209.5 c	566.5 c	0.999948	0.999858	0.000090
Ball screw assembly	0.0000000095/c	209.5 c	566.5 c	0.999998	0.999995	0.000003
Bellows	0.0000009/c	209.5 c	566.5 c	0.999811	0.999490	0.000321

TEST PROGRAM

During the previous report period, an injector face crack was discovered following completion of the first acceptance test series for engine No. 6. Subsequent to rebuild, a malfunction of the bipropellant valve occurred during the second series of acceptance tests. Acceptance tests were then concluded, although, the complete series of acceptance tests were not performed. Review of the end-item data package, including test data sheets, was accomplished, and the engine was accepted by representatives of NASA and S&ID. This engine was shipped to WSMR for scheduled firing tests.

A summary of significant waivers and deviations to the specification which effect the reliability and performance of this first firable engine are as follows:

1. Engine was not aligned during assembly.
2. Center of gravity was not determined.
3. Bipropellant valve acceptance test data were invalidated by subsequent rework.
4. Excessive external leakage of thrust chamber seals and through ablative material was evident.
5. Injector vibration acceleration and frequency was not recorded during tests.
6. Cold gimbaling tests were not conducted subsequent to acceptance hot firing.
7. Engine had excessive contaminant particle size and count.
8. Time required to develop 90-percent steady-state thrust is in excess of specification.
9. Engine start and shutdown transient total impulse, and run-to-run tolerance, are in excess of specification limits.
10. Derived vacuum performance rating cannot be substantiated due to insufficient valid test data at altitude conditions.

During the leak check preceding the first scheduled acceptance firing of engine No. 10, major damage to the engine assembly was sustained. An erroneous test procedure resulted in excessive loading of the injector attach flange and destruction of the injector, bipropellant valve, and thrust chamber. Test procedures have been corrected.

The first series of acceptance test firings subsequent to rebuild demonstrated unsatisfactory injector/ablative chamber compatability, requiring modification to the pattern of the injector. Subsequent to pattern rework and satisfactory completion of the acceptance firing, a leak developed in a brazed joint of this injector, and it was rejected. This is a recurring type of failure indicating that the welding process is marginal and that the inspection procedure is incapable of detecting unsound braze areas.

A face-ring crack was discovered in the next serialized injector scheduled for this engine. The most recently assigned injector has successfully completed leak tests and will be subjected to compatibility and C* tests at the end of this report period. Engine firing acceptance tests are now schedule in July for delivery in August.

SUBCONTRACTOR MANAGEMENT

Subcontractor management effort during this report period provided progress in the solution of problems in certain areas of subcontractor activity and delineation of remaining problems in other areas:

1. Refinements are being made to the sequential method of engine reliability assessment in order to provide a more accurate evaluation of achieved reliability from hot-firing test data at the specific reporting periods. Component reliability estimates are being derived from both components and system tests, and these estimates in conjunction with subsystem test results will be used to produce an independent engine reliability assessment. Current thrust chamber assembly reliability, based on hot firings, has shown no change from that reported for the previous quarter: 0.81 at a 50-percent confidence level, or 0.73 at the 90-percent confidence level. Figure 3-7 is a sequential plot of reliability for the six-month period, October 1963 through March 1964.

2. S&ID comments to the revised subcontractor reliability program plan have been incorporated. A letter of approval has been written.

Reliability predictions are being generated, based on a statistical elimination from the test sample, of failures for which specific corrective action has been instituted. The frequency of these predictions will indicate the rate of design progress.

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CALCULATED SEQUENTIAL SLOPE AND INTERCEPT FACTORS

CONFIDENCE LEVEL - 50% - (1 -β) Δβ = 0.10

P* FAILURE RATE	0.50	0.40	0.30	0.20	0.10	0.05	0.01	0.001	0.0001
RELIABILITY	0.50	0.60	0.70	0.80	0.90	0.95	0.99	0.999	0.9999
h/S TRIALS INTERCEPT	3.32	4.51	6.46	10.32	21.85	44.88	229.4	2326.	25000
S, SLOPE	0.4414	0.3490	0.2592	0.1710	0.0849	0.0424	0.0085	0.0008	0.0002

CONFIDENCE LEVEL - 90% - (1 -β) Δβ = 0.02

P* FAILURE RATE	0.50	0.40	0.30	0.20	0.10	0.05	0.01	0.001	0.0001
RELIABILITY	0.50	0.60	0.70	0.80	0.90	0.95	0.99	0.999	0.9999
h/S, TRIALS INTERCEPT	5.64	7.66	10.97	17.53	37.13	76.26	389.7	3951	42474
S, SLOPE	0.3678	0.2871	0.2105	0.1375	0.0675	0.0334	0.0067	0.0007	0.0001

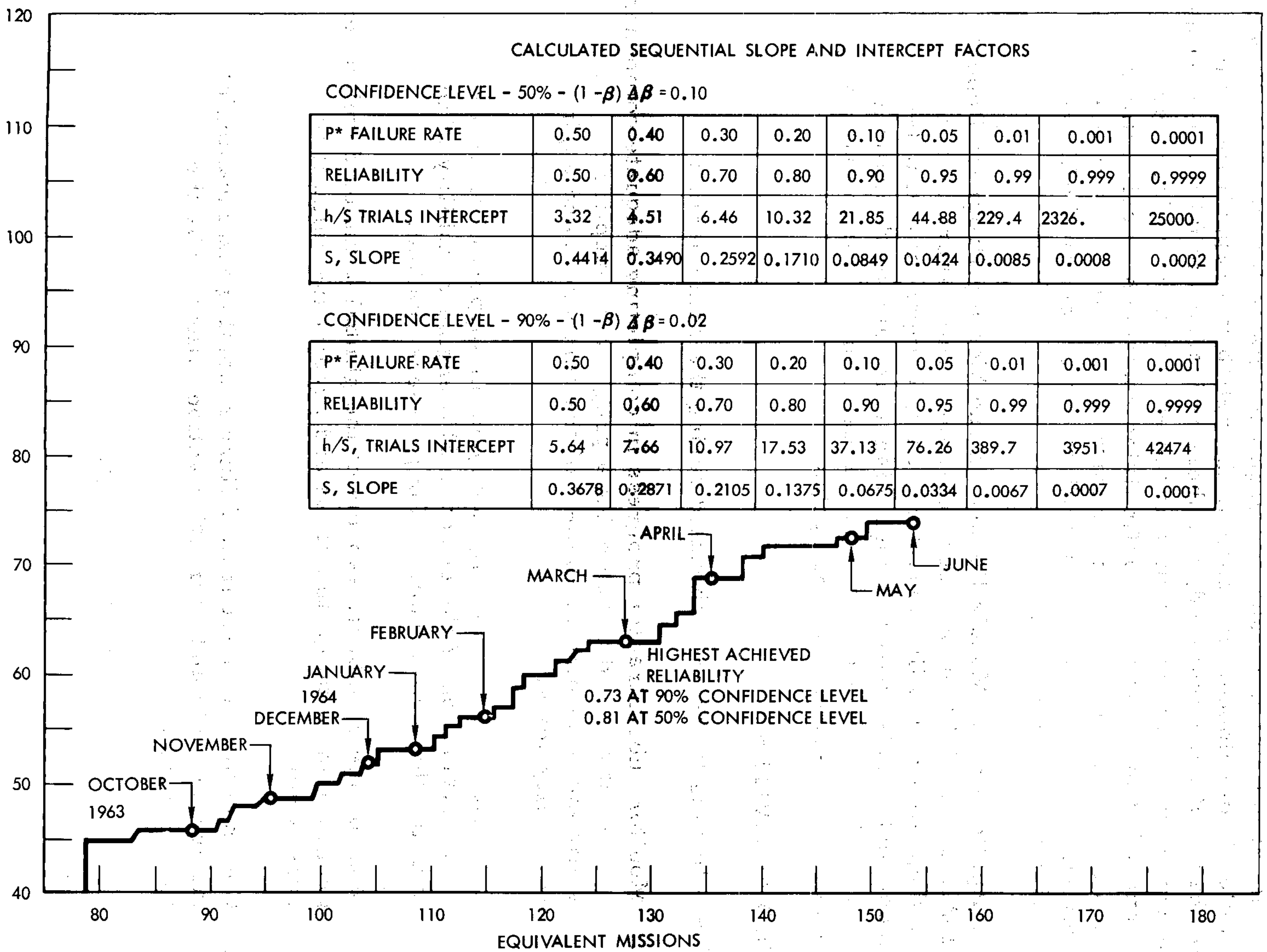

Figure 3-7. Service Module Service Propulsion System Sequential Growth Plot

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A review of the status of subcontractor control of its suppliers indicated that considerably more effort is necessary in this area. Component specifications imposing specific requirements on the suppliers have not been completely developed. In general, the reliability capabilities of the suppliers have not been assessed, and there is inadequate failure reporting from the suppliers. This situation is expected to change as increased effort is expended in updating and definitizing component specifications. The subcontractor has been directed to improve the effort in this area, since it is important that the component specifications reflect the S&ID procurement specification requirements.

The Apollo Service Module Rocket Engine Monthly Progress Report (3865-01-21, 30 April 1964) has been received. This report contains revised and updated reliability apportionments, component estimates, failure mode and effects analysis, logic diagrams, and mathematical reliability models. All state-of-the-art is determined for mission duty requirements of 750 seconds and 50 cycles.

PLANNED ACTIVITES

The following tasks are scheduled during the next quarter:

1. Monitor subcontractor progress in completing adequate component specifications and in achieving a program of supplier control sufficient to ensure attainment of the component and engine reliability goals.

2. Continue to perform design analyses in support of engineering; e.g., evaluation of the effect on SPS engine reliability of instrumenting the thrust chamber for pressure readout.

3. Monitor the reliability aspects of the gimbal actuator development program and attempt to assess and predict the reliability of that subsystem.

4. Continue to stress accurate failure reporting and meaningful failure analysis and corrective action follow-up by the subcontractor.

5. Assess impact of the dynamically stable injector program on engine reliability.

PROPELLANT MANAGEMENT

SUMMARY

Propellant management component suppliers were monitored for design evaluation, reliability implementation, and failure reporting requirements. Nonstandard electronic-part data sheets, specification control drawings, failure reports, failure analysis, and exempt parts lists were reviewed and analyzed.

Reliability studies were conducted on proposed changes to the propellant management for the Block II configuration.

ANALYSIS

SPS Helium Solenoid Valve

The service propulsion system helium solenoid valve problem previously reported (SID 62-557-9) was eliminated by specifying on the drawings a maximum allowable friction. It had been possible under maximum tolerance buildup for the poppet to bind.

The nonstandard and electronic parts list and the identification and traceability exempt parts list were reviewed. Because the above documents did not fulfill the procurement specification requirements, recommendations and comments were forwarded to the supplier.

SPS Helium Regulator

The revision of the specification flow requirements necessitated redesign of the SPS helium regulator by modifying the main metering section. The potential failure mode was jamming of the main metering piston due to reduced diametrical clearances. This design is currently being implemented, and another reliability analysis will be conducted when the supplier submits the design and test data.

The identification and traceability procedure was rejected, because it did not contain adequate control of the outside procurement and processing. The supplier's exempt parts list was approved.

SPS Propellant Utilization Gauging

Eighty-seven specification control drawings for high-reliability electronic components of the propellant utilization gauging system have been received to date, as part of the nonstandard part data justification for this system. Twenty-four specification control drawings were received and reviewed during this reporting period.

TEST PROGRAM

Components of the service propulsion propellant feed system are in the following stages of testing.

Testing	Component	1964 Completion Dates
Development	Quantity gaging system	September
Design verification	Pressurant disconnects	July
	Propellant disconnects	June
	Solenoid valve, helium	September
	Regulator, pressure, helium	September
	Check valve	September
	Connector, flexible	July
	Heat exchanger	July
Qualification	Test point coupling	September
	Pressurant reservoir	August
	Propellant reservoir	September
Off-limit	Relief valve, pressure, helium	June

All problems relative to test procedure approval for all SPS propellant feed subcontractors have been resolved.

Helium Pressure Regulator

Proposed surge pressure and regulation tests of the regulator and solenoid valve were reviewed and approved.

Helium Solenoid Valve

The solenoid coil shorted out during a dielectric strength test. The problem is currently being analyzed. The bubble displacement leak detection method has been analyzed, and procedures have been established.

RCS Regulators

As a result of a meeting in January 1964 with the supplier of the reaction control system regulators, the reliability logic and failure mode analyses have been received. The new logic has been reviewed, and comments are being forwarded to the supplier, so that the reliability numerical analysis can be submitted.

RCS Propellant Isolation Valve

The propellant isolation valve failed during testing. The switch indicated that the valve was functioning normally, when the poppet was actually jammed open. Redesign to correct this failure mode will be extensive, and the design alternate increases valve complexity, with the associated reliability degradation.

A study is in progress to examine the need for command module RCS component failure detection and to evaluate the reliability of the proposed redesign.

Block II Weight Reduction Studies

Cryogenic Helium Storage

The proposed cryogenic helium storage was reviewed. This system would require a more complex tanking and plumbing and an additional heat exchanger since no adequate heat supply exists in the service module. Additional problems of over-pressurization, double wall tank, additional fittings, and many more leak paths caused by the helium lines penetrating the outer wall would degrade system reliability.

Parallel Feed System

The parallel feed system would require additional equipment to prevent propellant transfer. Check valves or ball valves could be used to eliminate this problem, but reliability would be lowered. This approach would affect the design of the propellant utilization and gauging system. A redesign would be required, and two more zero-g retention devices would be added to each system.

Helium Disconnect

Review of data and examination of the disconnect showed excessive engagement forces following a design verification testing endurance failure. The problem was eliminated by a change in probe seal material. The disconnect had also experienced a leakage problem, because the silver plate flaked off the threads and worked under the seat. This problem was resolved by substitution of Brea lubricant for the silver plate.

Propellant Utilization System

A bi-metallic brazing problem was encountered with the service propulsion system flow control valve. This problem will be avoided by a change to an all-steel valve housing.

PLANNED ACTIVITIES

Systems compatibility tests have been scheduled on the SPS regulator and solenoid valve relative to component interrelationships which may have an effect on system reliability. Surge pressure effects resulting from fast activation of the solenoid valve and regulator flow, and the regulation phenomena resulting from the parallel regulator arrangement will be investigated.

Test program surveys, including test monitoring and test set-up inspection, are currently scheduled to be performed on all suppliers of SPS components. Sufficient data for initial reliability assessments should be accumulated for most components within the coming quarter.

The propellant compatibility test for the SPS solenoid valve has been successfully completed for a 14-day duration at 100 F. Current analysis of mission requirements indicate that specified duration and temperature requirements may be exceeded. Assurance of reliability will necessitate additional testing requirements.

Reliability has presented for review by cognizant groups explosion proof design and test requirements. The effect on reliability and the probability of possible explosion hazards is to be investigated.

Additional testing has been specified for the qualification test program for the SPS propellant and pressurant tanks; these include vibration tests on the propellant tanks, and helium leak test and creep tests on both the propellant and pressurant tanks. The additional vibration test was required because of a propellant tank design change incorporating a propellant retention reservoir. The helium leak detection and creep tests had not been performed previously.

The propellant utilization gauging system contract revisions will be negotiated.

IV. GROUND SUPPORT EQUIPMENT

SUMMARY

Reliability analyses were performed primarily on mission essential equipment (MEE). The most recent survey of the equipment lists shows 80 end items that are considered to be mission essential and are listed in Table 4-1.

Table 4-1. Mission Essential Ground Support Equipment

Unit	Category	Nomenclature
A14-019	ME I	Disconnect set, umbilical, spacecraft fluid/elect
A14-033	ME II	Test set, stimuli generator suit loop ECS
A14-034	ME II	Test set distribution, pressure ECS
A14-052	ME II	Heater power supply; fuel cell, cryogenic storage system
A14-139	ME I	Pyrotechnic initiators substitute unit
A14-148	ME II	Umbilical disconnect purge
A14-172	ME I	Umbilical disconnect set, S-IVB (LEM) adapter
C14-009	ME II	Crew systems checkout group
C14-019	ME I	Test conductor group
C14-051	ME I	Pyrotechnic BME
C14-075	ME I	Propulsion system fluid checkout unit
C14-112	ME I	C-band radar transponder checkout unit
C14-177	ME II	Electrical cable set, Launch Pad 37B
C14-180	ME II	Electrical cable set, Launch Pad 34
C14-187	ME II	Electrical cable set
C14-188	ME II	Electrical cable set
C14-189	ME II	Electrical cable set
C14-192	ME II	Umbilical junction box
C14-200	ME I	Carry-on receiver and baseplate unit
C14-201	ME I	Carry-on baseplate unit
C14-202	ME I	Junction box PACE - spacecraft carry-on
C14-210	ME II	Carry-on PCM system
C14-211	ME II	Digital signal conditioning and multiplexing unit
C14-212	ME II	Analog signal conditioning and sampling unit
C14-213	ME II	G&N signal conditioning and switching matrix unit

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Table 4-1. Mission Essential Ground Support Equipment (Cont)

Unit	Category	Nomenclature
C14-214	ME II	High-sampling-rate signal conditioning unit
C14-215	ME II	Special signal conditioning unit
C14-220	ME I	Carry-on command stimuli system
C14-230	ME II	Data interleaving system
C14-231	ME I	External digital test command system
C14-232	ME II	Miniaturized data interleaving system
C14-240	ME II	Servicing equipment ACE spacecraft adapter
C14-241	ME I	Service equipment digital test command system
C14-262	ME I	Power supply d-c ACE
C14-303	ME II	External signal conditioner
C14-410	ME II	Measurement set-space rad optical properties
C14-414	ME I	Launch control group
C14-446	ME I	Fluid distribution system control unit-CM RCS fuel
C14-447	ME I	Fluid distribution system control unit-SM RCS fuel
C14-448	ME I	Fluid distribution system control unit-RCS oxidizer
C14-449	ME I	Fluid distribution system control unit helium
C14-451	ME II	Earth landing system sequence controller pressure stimuli generator
C14-455	ME I	Service propulsion system remote control rack
C14-472	ME II	Electrical cable set, AMR Pad 34
C14-476	ME I	Fluid distribution system control unit, LH_2
C14-477	ME I	Fluid distribution system control unit, LO_2
C14-478	ME I	Fluid distribution system control unit fuel cell-water-glycol
C14-479	ME I	Fluid distribution system control unit, potable water
C14-480	ME I	Initiators stimuli unit
C14-484	ME II	External stimuli conditioning unit, SM
C14-488	ME I	Fluid distribution system control unit - SPS oxidizer
C14-489	ME I	Fluid distribution system control unit-SPS fuel
C14-492	ME I	Mission sequencer reset unit
C14-548	ME II	Electrical terminal distribution, Launch Complex 34, servicing tower fuel-side, CM
C14-549	ME II	Electrical terminal distribution, Launch Complex 34, servicing tower fuel-side, SM
C14-550	ME II	Electrical terminal distribution, Launch Complex 34, servicing tower oxidizer-side, CM

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Table 4-1. Mission Essential Ground Support Equipment (Cont)

Unit	Category	Nomenclature
C14-551	ME II	Electrical terminal distribution, Launch Complex 34, servicing tower oxidizer-side, SM
C14-572	ME I	Umbilical junction box, Florida Facility, Complex 34
C14-602	ME II	STU-SPS checkout and firing control
C14-605	ME II	STU-CM RCS checkout fire control console
C14-606	ME II	STU-SM RCS checkout fire control console
S14-002	ME I	N_2O_2 transfer unit and conditioning unit
S14-005	ME I	Water transfer unit
S14-008	ME I	Fuel transfer and conditioning unit
S14-009	ME I	Helium transfer unit
S14-019	ME I	Water glycol service set
S14-026	ME I	LH_2 transfer unit
S14-032	ME I	LO_2 transfer unit
S14-041	ME I	Fluid distribution system
S14-052	ME II	Water-glycol cooling unit
S14-053	ME I	Trim control set, water-glycol, ECS
S14-054	ME II	Fuel cell power plant, water-glycol servicing set
S14-057	ME I	RCS oxidizer servicing unit
S14-058	ME I	Fuel ready storage unit
S14-059	ME I	Oxidizer ready storage unit
S14-063	ME I	SM RCS fuel servicing unit
S14-064	ME I	CM RCS fuel servicing unit
S14-065	ME I	LO_2 mobile storage unit
S14-066	ME I	LH_2 mobile storage unit
S14-079	ME II	Module leak-test unit, potable

DEFINITIONS

ME I - Mission Essential, Criticality I. GSE which, if it failed or failed to detect, could cause a failure that could jeopardize crew safety or create a personnel hazard.

ME II - Mission Essential, Criticality II. GSE which, if it failed, could result in extended launch delays for repairs; and if undetected, in mission abort.

MS - Mission Support. Mission Support GSE which, if it failed, would not result in unsafe conditions, long-lead repairs, or launch delays.

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Table 4-2. Failure-Mode and Effect Analysis—Ground Support Equipment

Unit	Category	Nomenclature
C14-192	ME II	Umbilical junction box
C14-211*	ME II	Digital signal conditioning and sampling unit
C14-212*	ME II	Analog signal conditioning and sampling unit
C14-213*	ME II	G&N signal conditioning and switching matrix unit
C14-214*	ME II	High-sampling-rate signal conditioning unit
C14-215*	ME II	Special signal conditioning unit
C14-444*	MS	Fluid distribution system control unit, SPS oxidizer
C14-445*	MS	Fluid distribution system control unit, SPS fuel
C14-446*	ME I	Fluid distribution system control unit, CM RCS fuel
C14-447*	ME I	Fluid distribution system control unit, SM RCS fuel
C14-448*	ME I	Fluid distribution system control unit, RCS oxidizer
C14-449*	ME I	Fluid distribution system control unit, helium
C14-476*	ME I	Fluid distribution system control unit - LH_2
C14-477*	ME I	Fluid distribution system control unit LO_2
C14-478*	ME I	Fluid distribution system control unit, fuel cell - water-glycol
C14-479*	ME I	Fluid distribution system control unit, potable water
C14-484*	ME II	External signal conditioning unit, SM
C14-488*	ME I	Fluid distribution system control unit - SPS oxidizer
C14-489*	ME I	Fluid distribution system control unit - SPS fuel
C14-605	ME II	Special test unit, CM RCS checkout-fire control console
C14-606	ME II	Special test unit, SM RCS checkout-fire control console
S14-026**	MEE I	LH_2 Transfer unit
S14-032**	MEE I	LO_2 Transfer unit
S14-002**	ME I	N_2O_2 Transfer unit
S14-008**	ME I	Fuel transfer unit

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Table 4-2. Failure-Mode and Effect Analysis—Ground Support Equipment (Cont)

Unit	Category	Nomenclature
S14-041	ME I	Fluid distribution unit
S14-052**	ME II	Water-glycol cooling unit
S14-079**	ME II	Module leak test unit

*Preliminary data
**Updated from previous reports

Table 4-3. Reliability Prediction—Ground Support Equipment

Unit	Category	Nomenclature	MTBF Goal (hours)	Prediction MTBF (hours)
A14-074	MS	Load bank, electrical	300	594
A14-139	ME I	Pyrotechnic initiator substitute unit	600	3240
C14-032	MS	Antenna checkout group	300	2107
C14-075	ME I	Propulsion system fluid checkout unit	600	844
C14-089	ME II	Mobile data recorder	600	430
C14-192	ME II	Umbilical junction box	600	2179
C14-438	MS	Junction box, electrical	300	8102
C14-455	ME I	Service propulsion system, remote control rack	600	1500
C14-605	ME II	Special test unit, CM RCS checkout-fire control console	600	675
C14-606	ME II	Special test unit, SM RCS checkout-fire control console	600	840
C14-608	MS	Special test unit, fuel cell cryogenic system	300	305
C14-611	MS	Special test unit, communication and data subsystem	300	2272
C14-613	MS	Special test unit, test conductor's console	300	1644
C14-614	MS	Special test unit, environmental control system	300	879
C14-615	MS	Special test unit, cryogenic oxygen servicing	300	1840

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Table 4-3. Reliability Prediction—Ground Support Equipment (Cont)

Unit	Category	Nomenclature	MTBF Goal (hours)	Prediction MTBF (hours)
C14-617	MS	Special test unit, electrical power system	300	518
C14-427	MS	Fluid calibration unit	300	839
S14-005	ME I	Water transfer unit	600	6624
C14-240	ME II	ACE spacecraft adapter servicing equipment	600	2950
S14-002	ME I	N_2O_2 transfer unit	600	750
S14-008	ME I	Fuel transfer unit	600	750
S14-052	ME II	Water-glycol cooling unit	600	646
S14-057	ME I	RCS oxidizer servicing unit	600	106
S14-063	ME I	SM RCS fuel servicing unit	600	106
S14-064	ME I	CM RCS fuel servicing unit	600	106
S14-079	ME II	Module leak test unit	600	8011
S14-026*	MEE I	LH_2 transfer unit	600	628
S14-032*	MEE I	LO_2 transfer unit	600	608

*Updated from previous reports

ANALYSIS

The reliability effort on mission essential (ME) and mission support (MS) equipment for each boilerplate and airframe is current with Master Development Schedule 7. An analysis performed on each successive spacecraft will be used to update the successive MEE and MSE analyses. There is an increase in the amount of MEE, from three units on Boilerplate 6 to 80 units on Airframe 011 (Table 4-2). Reliability figures have been calculated for the countdown period using failure-rate data obtained from the reliability prediction on each boilerplate and airframe (Table 4-3). This procedure and the test assessment data furnish a periodic check on the reliability attained for each boilerplate and airframe, and will be used as an aid in support of Airframe 011. The GSE reliability analyses of Boilerplates 6, 12, and 13 have been completed, and an analysis is in process for Boilerplate 14.

The analysis being performed on Boilerplate 14 is significant in that a high percentage of Boilerplate 14 equipment will be used in later manned vehicles.

Table 4-4 defines the GSE failure-mode and effect analysis, criticality, corrective action, and failure mode classification.

Table 4-4. Failure Mode and Effect Analysis—GSE Criticality, Corrective Action, and Failure Mode Classification

Criticality Categories	Failure Mode Order	Corrective Action Classification (CAC)
Catastrophic	First-order failure mode: Failure of a GSE component which results in personnel hazard or a spacecraft failure, detected or undetected. Loss of equipment by damage.	Unit will be out of service, and will be removed from work area while failed component is being replaced.
Major	Second-order failure mode: Failure of a GSE compo-	Unit will be out of service while replacement or repairs are being made. It may be

Table 4-4. Failure Mode and Effect Analysis—GSE Criticality, Corrective Action, and Failure Mode Classification (Cont)

Criticality Categories	Failure Mode Order	Corrective Action Classification (CAC)
	nent which results in extended delay of servicing or checkout function.	necessary to remove unit from work area.
Minor	Third-order failure mode: Failure of a GSE component which results in temporary delay of servicing or checkout functions.	Minor adjustments or repairs will be made while the servicing or checkout function continues. It will not be necessary to remove unit from work area.
All others	Fourth-order failure mode: Failure of a GSE component which results in no delay in servicing or checkout function.	No corrective action required until servicing or checkout function is completed.

C14-192 UMBILICAL JUNCTION BOX

A preliminary failure mode and effect analysis was performed on the C14-192 umbilical junction box (Table 4-5). The second-order failure mode of the junction box failing could cause a heavy current flow, resulting in overheating and an improper power supply to the spacecraft. Further investigation indicated that should this condition occur it would immediately be detected by the monitoring Launch Control Group. Consequently, no design change was contemplated at this time

ACE RESPONSE

Preliminary failure mode and effect analyses were performed on the various units of the ACE response subsystem. The subsystem's primary function is to condition, sample, digitize, and assemble analog and digital spacecraft ground checkout data and servicing equipment data, and to interleave this data with the Apollo airborne PCM data outputs for transmittal to the control room to verify that the spacecraft systems are in flight readiness. All listed units are classified as mission essential equipment and will be used for Boilerplate 14 and Airframes 006, 008, 009 and 011.

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Table 4-5. Failure Mode and Effect Analysis Summary (C14-192)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Undetectable failure of a GSE component which results in its replacement or repair.			15			15			15	
Detectable failure of a GSE component which results in its replacement or repair.		1	19			5	15		19	1
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.										
Totals		1	34			20	15		34	1
Sum totals	35				35				35	

The C14-211 digital signal conditioning and multiplexing unit accepts various voltage level event signals and pulses from spacecraft systems, conditions these signals, and samples them in turn, as required by format timing. A summary of the results of the preliminary FMEA performed on a functional block basis is given in Table 4-6. Since a failure in the power converter submodule could result in a loss of all information from this unit and since the power converters would also contribute to the unit's heat and failure rate problem, the following suggestions were submitted: (1) supply redundant ±18-volt d-c line from an external power supply; (2) eliminate power converters and supply ±18 volt d-c from an external source; or (3) use redundant power converters.

Since the multiplexer logic circuitry unit contributes very highly to the total failure rate of the unit (205. 57 percent per 1000 hours), reduction of its logic circuitry elements by reorganization was recommended.

The results of preliminary FMEA are summarized as follows: C14-212, signal conditioning and sampling unit, Table 4-7; C14-213, signal conditioning and switching matrix unit guidance and navigation, Table 4-8; C14-214, high rate signal conditioning unit, Table 4-9; and C14-215, special signal conditioning unit, Table 4-10.

Due to the allocated maximum-volume envelopes assigned to all carry-on signal conditioners, Models C14-211 through C14-215, it may not be possible to increase their reliability by component redundancy. Improvement could be accomplished by the following methods: (1) simultaneous transmittal of critical signals through more than one signal conditioner, utilizing unassigned channels; (2) utilization of valves computer-complex equipment for fault isolation purposes in conjunction with preprogrammed tapes; or (3) adequate field spares provisioning, drawers, submodules, etc.

FLUID DISTRIBUTION SYSTEM CONTROL UNITS

FMEA were performed on the fluid distribution control units (FDSCU): C14-446, C14-447, C14-448, C14-449, C14-476, C14-477, C14-478, C14-479, C14-488, C14-489. The summary of the analysis appears in Table 4-11. These units will be used for controlling the operation of the fluid distribution valves, monitor valves, fluid sensor parameters, and other parts of the control system.

An evaluation of the functional requirements of these units indicated that there are to be no first-order failure modes and one possible second-order failure mode. Failure of the +28-volt d-c supply source would make control and monitoring of the FDSCU impossible. If the FDSCU or ACE inputs become grounded, the monitoring capabilities of both units are lost for the grounded input channel. It was recommended that provisions be made to

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Table 4-6. Failure Mode and Effect Analysis Summary (C14-211)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.		16	1			16	1		17	
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.										
Totals		16	1			16	1		17	
Sum totals	17				17				17	

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Table 4-7. Failure Mode and Effect Analysis Summary (C14-212)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.			12			12			12	
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.										
Totals			12			12			12	
Sum totals	12				12				12	

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Table 4-8. Failure Mode and Effect Analysis Summary (C14-213)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.			10			10			10	
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.										
Totals			10			10			10	
Sum totals	10				10				10	

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Table 4-9. Failure Mode and Effect Analysis Summary (C14-214)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.			8			8			8	
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.										
Totals			8			8			8	
Sum Totals	8				8				8	

Table 4-10. Failure Mode and Effect Analysis Summary (C14-215)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.		10				10			10	
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.				1				1	1	
Totals		10		1		10		1		
Sum totals	11				11				11	

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Table 4-11. Failure Mode and Effect Analysis Summary (C14-446, C14-447, C14-448, C14-449, C14-476, C14-477, C14-478, C14-479, C14-488, and C14-489)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.					1					
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.		1	109			102	7			
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.				3				3		
Totals		1	109	3	1	102	7	3		
Sum totals	113				113					

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isolate these units, and that consideration be given to a source of +28-volt d-c power that is situated external to the subject models. A voltage failure would be a second-order detectable failure mode.

LH_2 AND LO_2 TRANSFER UNITS (S14-026 & S14-032)

The failure mode and effect analysis of the LH_2 and LO_2 transfer units has been updated. Because of their similarity, only one analysis was performed for both units, using flow schematics and electrical schematics received from the supplier. The analysis covers: (1) the pretransfer purge with GHe, (2) the pretransfer purge with the applicable gaseous medium (GH_2 or GO_2), (3) the transfer of the liquid medium, LH_2 or LO_2, (4) the post-transfer drain, and (5) the purge operation.

As shown in Table 4-12, 158 failure modes were reviewed. There are 3 relief-valve, 2 filter, and 11 quick-disconnect-coupling failure modes that fell into the first-order failure category in each unit (9 of which are undetectable). There are 8 second-order failure modes that are undetectable; these are filter, check-valve, and quick-disconnect-coupling failures. The supplier should utilize valves with Kel-F seats, high-reliability quick-disconnect couplings, and filters to preclude the probability of these failure modes.

This analysis covered all mechanical, electromechanical, and electrical components and equipment used in the LH_2 and LO_2 transfer units (Models S14-026 and S14-032).

The electrical subsystems will be housed in an enclosed cabinet that will be purged and filled with nitrogen to protect the electromechanical and electrical equipment from oxidation and extreme environmental factors. To further ensure high reliability, portions of the GSE are being redesigned, and measures have been taken to ensure that critical components are so located as to minimize maintenance problems.

EARTH LANDING SYSTEM GSE

A preliminary failure mode and effect analysis was performed by the subcontractor on the C14-451 pressure stimuli generator. The unit will be used to support Boilerplates 14, 22, and 23, and Airframes 002, 006, 008, 009, 010, and 011. This unit provides a vacuum for cycling the sequence controller through simulated altitudes. The unit, when connected with the C14-452 electrical test stand, forms a system that will monitor the circuits that are required to check out the sequence controller. The stimuli generator has the following capabilities and characteristics:

1. Evaluates the atmosphere from the sequence controller baroswitch manifold to at least 2 in. Hg within 5 minutes.

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Table 4-12. Failure Mode and Effect Analysis Summary (S14-026 and S14-032)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage	9				-	9			6	3
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.	10				-	10			1	9
Undetectable failure of a GSE component which results in its replacement or repair.		8	-		-	8			1	1
Detectable failure of a GSE component which results in its replacement or repair.		22	89			79	32		79	29
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.			-	20			-	2	-	-
Totals	19	30	89	20	-	106	32	20	87	42
Sum totals	158				158				129	

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2. Regulates the repressurization of the manifold to ambient atmospheric pressure and displays the pressure of the manifold.

3. Uses four modes of operation—climb, hold, descend, and fast descend.

4. Simulates the various atmospheric pressures encountered during launch, abort, and reentry of the Apollo command module.

5. Goes into hold mode whenever power is applied to the stimuli generator.

6. Has self-test provisions capable of isolating malfunction to a major component.

7. Has provisions for local control or remote-control operation.

The summary of the FMEA is presented in Table 4-13. The following restraints are being reviewed in order to eliminate or reduce the first- and second-order failure modes:

1. Pressure Transducer. Select components for high reliability. Examine supplier's testing procedure. Provide temperature control and periodic calibration.

2. Circuit Breakers. Use sealed units to eliminate contamination due to atmospheric conditions.

3. Switch, POWER ON. Change electrical design to permit automatic shutoff.

4. Relays. Provide mercury-type relays in sealed units.

5. Thermostats. Select components for high reliability. Examine supplier's testing procedure. Provide two thermostats in series (redundancy).

6. Indicator, Hot. Provide four lamps in parallel. Include indicator in the lamp-test circuit.

7. Digital Voltmeter. Select unit for high reliability. Provide periodic calibration of external test voltage and qualification testing.

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Table 4-13. Failure Mode and Effect Analysis Summary (C14-451)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.	7				7				7	
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment damage.	2				-	2			4	
Undetectable failure of a GSE component which results in its replacement or repair.		6	4		-	10			20	
Detectable failure of a GSE component which results in its replacement or repair.		44	40			22	62			
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.			-	-			-	-	-	-
Totals	9	50	44	-	7	34	62		31	-
Sum totals	103				103				31	

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8. Resistors and Capacitors. Select components for military specification and high reliability. In-house testing for tolerance capabilities.

COMMAND AND SERVICE MODULE RCS CHECKOUT AND FIRE CONTROL CONSOLE

A failure mode and effect analysis on C14-605, and C14-606 (Table 4-14) was performed. This equipment will be used for ground, simulated, and preflight checkouts of the reaction engines of the command and service modules.

There were five first-order failure modes. Two involved gating diodes. An open in these diodes would affect the fuel valve operation; one valve would remain active, and the other would remove the shutdown signal. Redesign eliminated the hazard. Two relays were involved in another first-order failure mode. If these relays failed (open), the emergency shutdown signal would be disabled, and the fuel valves would remain active. This was redesigned into a lower-order failure mode. One switch failure (open) would cause a first-order failure mode. The isolation valves could not be operated from the control panel; redesign will eliminate this.

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Table 4-14. Failure Mode and Effect Analysis Summary (C14-605 and C14-606)

Criticality Classification	Failure Mode Order				Corrective Action Classification				Failure Effect Operation	
	1	2	3	4	1	2	3	4	Delays	Halts
Undetectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.										
Detectable failure of a GSE component which results in spacecraft failure, personnel hazard, or loss of equipment by damage.	5					5				
Undetectable failure of a GSE component which results in its replacement or repair.										
Detectable failure of a GSE component which results in its replacement or repair.										
Undetectable or detectable failure of a GSE component which results in minor adjustments or maintenance.										
Totals	5					5				
Sum totals	5				5					

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V. SPECIAL STUDIES

BLOCK II CONFIGURATION STUDY

The Block II configuration changes represent both significant mission changes and subsystem design changes to effect an overall reduction of the Apollo spacecraft launch weight. The Block II configuration changes were combined into four mission configurations—A, B, C, and D—with each consecutive configuration imposing greater impact on costs and schedules.

A reliability evaluation of each configuration has shown that the most significant change affecting reliability was the reduction from a 14-day to a 10-day mission. This mission change accomplished an increase in both mission success and crew safety reliability.

The configuration providing the maximum increase in reliability was the Block II-D which represented all of the subsystem changes existing in the Block II-C configuration with the addition of the vernier engine system as a backup mode to both the service propulsion subsystem (SPS) and the service module reaction control subsystem (SM RCS).

The Block II configurations proposed included a mission change from a free return to a nonfree return trajectory, providing a weight reduction equivalent to 1231 pounds of dry command service module launch weight. However, the nonfree return trajectory eliminates the use of the SM RCS as a backup to the SPS in abort missions occurring during the translunar coast phases of the mission, thus increasing crew losses by about 2000 per million missions. To resolve this problem, a rigorous propulsion backup trade-off study was conducted to determine the optimum propulsion backup configuration. The results of this study indicated that a configuration utilizing the LEM descent propulsion stage and the vernier engine system provided the greatest potential for reliability growth with the minimum system complexity.

In support of the Block II configuration change proposal, a series of reliability studies was conducted to evaluate both individual subsystem configuration changes and a group of overall mission configurations. The results of the configuration analyses as well as the previously mentioned propulsion backup trade-off study are discussed in the following sections of this report.

MISSION MODEL

To illustrate the effects of the Block II proposed configuration on the reliability of the Apollo LOR mission, a model was developed reflecting both the mission success and crew safety reliabilities because many of the proposed configuration changes affect only the crew safety reliability. To establish a mission model that would properly reflect the reliability effects on the mission, both the boost vehicle and the lunar excursion model reliability were included. To better evaluate the configuration changes, subcontractor estimates and handbook state-of-the-art failure rate data were used, taking into account the degree of reliability growth for the subsystems expected.

A reliability of 0.95 per boost vehicle represents the expected booster reliability; therefore, this value used for each booster resulted in a reliability of 0.857 for the three boost vehicles. In addition, it was assumed that half of the S-IVB failures would occur during translunar injection resulting in mission aborts early in the translunar coast phases.

Estimated mission success and crew safety reliabilities for the lunar excursion module were taken from Tables 1.3 and 1.5 in the Grumman Aircraft Engineering Corporation Quarterly Status Reliability Report, LPR 550-3. These tables indicated a reliability of 0.8942 for mission success and, a reliability of 0.9928 for crew safety for the lunar excursion module (LEM).

The model used for the configuration analyses was divided into eight major phases to reflect the variability in abort mission lengths necessary to indicate the effects of the change to a nonfree return trajectory and the use of the various combinations of propulsion backups. The mission time lines used in the analysis are the present 14-day LOR mission, the proposed 9.7-day LOR mission utilizing a free return trajectory, and the proposed 10.6-day LOR mission utilizing a nonfree return trajectory.

Mission success for all the mission configurations considered was defined as the completion of a lunar landing, minimum lunar exploration (2-hour lunar stay) without a mission abort, and a subsequent safe return of the crew to earth. Crew safety for all the configurations considered was defined as the sum of the mission success reliability plus the product of the probability of mission abort and the probability of safely aborting. Safe abort consists of the command module returning to earth prior to the scheduled time and landing safely without the crew being exposed to environments that exceed the emergency limits. The abort criterion utilized in the analysis assumed that the mission will be aborted if sufficient failures occur in operating systems or equipment so that one additional failure would eliminate the capability of safe abort.

The assumption made in the mathematical representation of the subsystems reliability in the model produced a lower bound reliability estimate; thus, the model represents validly the minimum mission success and crew safety reliabilities.

MISSION CONFIGURATION ANALYSIS

The Block II-A, B, C, and D configurations used in this study included the mission change from 14 to a 10-day design mission and the use of LEM propulsion backup to the service propulsion system, in all four configurations, as well as the hardware changes (Table 5-1) for each specific configuration.

Table 5-1. Block II Configurations

Change Description	Configuration			
	II-A	II-B	II-C	II-D
Launch escape system				
Boost protective cover, soft	x	x	x	
Canard surfaces	x	x	x	x
Pitch motor cut-out beyond low-altitude aborts	x	x	x	x
Reduce ballast in LES (from 1500 to 1000 pounds)	x	x	x	x
Reduce ablator on tower legs	x	x	x	
Relocate tower wells to station 100, shorten tower legs, redesign tower		x	x	
Hard aerodynamic-load-bearing boost cover with fiberglass monocoque LES tower and command module-service module jettisonable fairing				x
Launch escape motors rotated 45 degrees				x
Command module design				
Center-of-gravity location to provide lift-to-drag >0.42 (Goal 0.46)	x	x	x	x
Single-point flotation	x	x	x	x

Table 5-1. Block II Configurations (Cont)

Change Description	Configuration			
	II-A	II-B	II-C	II-D
Flotation bag as required	x	x	x	x
Add LEM docking provisions	x	x	x	x
Replace heat shield castings with weldments	x	x	x	x
Relocate LEM umbilical		x	x	
Tunnel design refined, retain 29 inches diameter	x	x	x	
Relocate forward pitch engines		x	x	x
Reduce window thickness	x	x	x	x
Redesign thrusters		x	x	x
Replace copper vent with beryllium			x	x
Use titanium in "pork chop" frames			x	x
Revise structural criteria		x	x	x
Redesign secondary structure, as required	x	x	x	x
Replace paint			x	x
Reduce SC: Equal weight and volume	x	x	x	x
Relocate command module-service module umbilical				x
LEM—docking aids and rendezvous displays	x	x	x	x
Earth landing system				
Repackage parachutes for Block I, suitable for flat cut-off at station 109	x			
Repackage parachutes for cut-off at station 100		x	x	

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Table 5-1. Block II Configurations (Cont)

Change Description	Configuration			
	II-A	II-B	II-C	II-D
Redesign ELS arrangement - (flower-pot, single-point attachment, etc.)		x	x	
Repackage for no tunnel				x
Heat shield				
Thermal control paint on ablator (to reduce bond line initial temperature from 250 to 150 F)	x	x	x	x
Fix possible gap problem at station 081 and 023	x	x	x	x
Increase ablator around tower wells at station 081	x			
Eliminate heat short from inner structure at station 043	x	x	x	x
Consider raising blunt face bond line temperature from 600 to 800 F				
Permit 600 F blunt face bond line temperature at chute deployment	x	x	x	x
Revise Ablator thickness	x	x	x	x
Redesign crew compartment heat shield (6-panel)				x
Environmental control system				
LiOH bypass (10 cfm at 3.5 psia per man)	x	x	x	x
Free condensate control	x	x	x	x
Redundant cooling loops on crew safety critical systems	x	x	x	x
Radiator tolerance of temperature limits (propose liquid Freon secondary loop)	x	x	x	x

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Table 5-1. Block II Configurations (Cont)

Change Description	Configuration II-A	II-B	II-C	II-D
Meteoroid protection on radiators	x	x	x	x
Water transfer line to LEM (made possible by Freon loop)	x	x	x	x
Communications				
Flush-mounted S-band omni-antennas on command module	x	x	x	x
VHF antenna from command module to service module	x	x	x	x
Redesign whip antenna for HF only	x	x	x	x
Add rendezvous radar and transponder (including antennas, controls, and displays)	x	x	x	x
Humidity fix, interim				
Humidity fix, final minimal	x	x		
Humidity fix, final complete			x	x
Eliminate all spares	x	x	x	x
Redesign CTE and up-data link for MSFN updating	x	x	x	x
Delete VHF-FM transmitter	x	x	x	x
Delete UHF command receiver	x	x	x	x
EVA conferencing/communication	x	x	x	x
Add LEM docking umbilical	x	x	x	x
Final fix and repackaging	x	x	x	x

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Table 5-1. Block II Configurations (Cont)

Change Description	Configuration			
	II-A	II-B	II-C	II-D
PM - transmission except television	x	x	x	x
EVS communication checkout	x			
Receive/record LEM PCM	x			
Time correction of recorded voice	x			
Up-data link direct display	x			
Simultaneous real-time and recorded PCM	x			
Delete C-band antenna	x	x	x	x
Delete SCIN from command module	x	x	x	x
Redesign SCIN for service module	x	x	x	x
Repackage communication systems	x	x	x	x
Provide switchable redundancy	x	x	x	x
Add ground command communication modes	x			
Add extravehicular transfer aids (life systems)	x	x	x	x
Electrical power system				
Add dc-dc regulator	x	x	x	x
Cyro reactants for 14-day earth orbital mission	x	x	x	x
Humidity fix, interim				
Humidity fix, final minimal	x	x		
Humidity fix, final complete			x	x

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Table 5-1. Block II Configurations (Cont)

	Configuration			
	II-A	II-B	II-C	II-D
Postlanding battery	x	x	x	x
Ripple filter	x	x	x	x
Reduce wire size and insulation thickness		x	x	x
Redesign cryogenic reactant storage for improved insulation and single tanks			x	x
Use two fuel cells versus three			x	x
Repackage entry and postlanding batteries		x	x	x
Fuel cell power in lieu of pyrotechnic battery power for service module separation	x	x	x	x
Guidance and navigation				
Use Block II G&N	x	x	x	x
Humidity fix, final complete	x	x	x	x
Eliminate all spares	x	x	x	x
Eliminate main display keyboard (DSKY) for computer	x	x	x	x
Study minimum integrated G&N and SCS	x	x	x	x
G&N interface to S-IVB IU for back-up control				
Injection into earth orbit	x	x	x	x
Translunar injection	x	x	x	x
Stabilization and control system				
Humidity fix, interim				
Humidity fix, final minimal	x	x		
Humidity fix, final complete			x	x

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Table 5-1. Block II Configurations (Cont)

	Configuration			
	II-A	II-B	II-C	II-D
Add LEM body bending compensation filter for TVC	x	x	x	x
Add director and response tester (DART), unmanned missions	x	x	x	x
Eliminate all spares	x	x	x	x
Provide switchable redundancy	x	x	x	x
Increase command module roll rate capability during entry (from nominal 20 degrees per second to 20 degrees per second minimum)	x	x	x	x
Improve minimum impulse (from 10 to 2.4 arc minutes per second)	x	x	x	x
Refine SCS design (including repackaging)	x	x	x	x
Service module design				
Micrometeoroid protection	x	x	x	x
Add three flush-mount VHF antennas	x	x	x	x
Integrate RCS heat shield with structure		x	x	x
Passive thermal control system (TCS)	x		x	x
Active thermal control system (TCS)	x	x		
Clean-up structural details	x	x	x	x
Revise structural criteria		x	x	x
Replace paint			x	
Off-load present service module	x			
Maintain present service module length, shorten tanks, and clean up structure		x		

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Table 5-1. Block II Configurations (Cont)

	Configuration			
	II-A	II-B	II-C	II-D
Shorten service module length, shorten tanks, and clean up structure			x	x
Reduce tank pressure tolerances (from 240 to 225 psi maximum)		x	x	x
Service propulsion system				
Add insulation and redesign for passive TCS	x		x	x
Retain series SPS feed system and add structural stiffness, as required	x	x		
Add four aft vernier engines for SPS backup				x
Reduce helium quantity for shortened propellant tanks; retain He tank size		x	x	x
Change to monomethyl hydrazine (MMH) propellant		x	x	x
Refine engine design (weight and reliability)			x	x
Change to a parallel feed system			x	x
Reduce propellant load	x	x	x	x
Use cryogenic helium storage				x
Adjust He quantity and tank thickness for chamber pressure decay		x	x	x
Reaction control system—service module				
Add insulation and redesign for passive SCS	x	x	x	x
Add MMH propellant	x	x	x	x
Spacecraft-LEM-adapter (SLA)				
Provide service module destruct system	x	x	x	x
Redesign for partly jettisonable SLA				x

The changes having a significant reliability effect are covered in the Configuration Discussions. In addition to the reliability analysis of the configurations, a reliability analysis of both the 10-day and the 14-day LOR missions, using a free-return trajectory the existing spacecraft configuration, and state-of-the-art failure rates, were conducted to reflect the changes in mission time length. This reduction of mission length resulted in a decrease of 37,000 mission losses and 26,000 crew losses per million missions.

To reflect the significance of the subsystem design changes resulting in weight reduction, the 10-day mission was used for a baseline. The changes in mission and crew losses per million missions are shown in Table 5-2 for each configuration. However, it should be noted that because of the reduction in mission length, the overall reliability of each of the proposed configurations is increased.

CONFIGURATION DISCUSSIONS

Block II-A Configuration

The significant subsystem changes affecting reliability in the Block II-A configuration are found in the ECS, SM RCS, and electronics subsystems. Although there were no significant changes to the SPS, the use of the LEM ascent and descent engines, as propulsion backup to the SPS prior to lunar landing, significantly reduced the number of expected crew losses due to a failure of the SPS. Propulsion backup did not affect the mission success reliability.

The subsystems contributing the greatest increases in mission losses were the electronics, ECS, and SM RCS, in that order. The ECS caused the major increase in crew losses. The reliability degradation in the electronics subsystem was primarily caused by the increased operating time of the communications subsystem being utilized as primary navigational equipment.

The reliability degradation caused by the ECS is primarily the result of establishing a central cooling system for the fuel cells; they previously contained their own cooling systems. While this increased the fuel cell reliabilities, and a redundant cooling loop was included in the ECS, the overall effect of this change increased both mission and crew losses. The mission losses increased because the mission abort criteria for the old system allowed two of these cooling loops to fail before an abort was required; whereas, in the new system, an abort will be initiated when a single coolant loop failure occurs. The crew loss increase occurs because the previous configuration required three coolant loop failures before system failure and subsequent crew loss; whereas, in the new system, a crew loss will result from two failures.

The reliability degradation due to the SM RCS results from the addition of an active temperature control system on the RCS engine which, in certain failure modes, causes premature mission aborts. However, this change would not affect the crew safety reliability of the vehicle.

Block II-B Configuration

The Block II-B configuration includes the mission configuration of Block II-A and some additional subsystem changes. An evaluation indicated that these proposed additional subsystem changes would have no significant affect on mission success or crew safety reliability. Thus, the mission success and crew safety reliabilities for the Block II-B configuration are the same as the Block II-A configuration.

Block II-C Configuration

The Block II-C configuration includes all the subsystem changes of Blocks II-A and II-B. The mission configuration is also the same, except that the inclusion of a parallel feed for the SPS results in a reduction of the lunar orbit abort mission length from 105 to 50 hours for aborts occurring prior to LEM separation by allowing the use of both the LEM ascent and descent propulsion engines to inject into transearth coast.

As seen in Table 5-2, the reliability evaluation of the Block II-C configuration shows an increase in both mission success and crew safety reliabilities. The increase in mission success is due primarily to the addition of the electrical ball valve actuation system in the SPS. The increase in crew safety reliability reflects both the improvement in the SPS and the improvement in the probability of safely aborting from lunar orbit realized by reducing the abort mission length.

The increase in mission success and crew safety reliabilities were reduced somewhat by the configuration change in the cryogenic storage subsystem from a dual-tank system to a single-tank system. However, the proposed single-tank configuration is more reliable in mission success than the previous dual-tank configuration. The reduction in mission success reliability seen in Table 5-2 resulting from premature aborts is due to the pressure sensing devices which are redundant in the dual configuration, but in series in the proposed configuration.

Block II-D Configuration

The configuration change between the Block II-D and the previously discussed configurations is the addition of the vernier engine system to back up the SPS.

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Table 5-2. Configuration Analysis

Apollo LOR Mission Configuration	Mission Success Losses per 10^6 Missions		Crew Safety Losses per 10^6 Missions	
	Losses	Change From Present	Losses	Change From Present
10.8 day, present profile, maximum nonfree return	288,300		45,400	
10.8 day, Block II-A	313,400	+25,100	56,800	+11,400
10.8 day, Block II-B	313,400	+25,100	56,800	+11,400
10.8 day, Block II-C	311,100	+22,800	55,800	+10,400
10.8 day, Block II-D	310,000	+22,000	54,300	+ 8,900

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[redacted]

The reduction of both mission and crew losses in the Block II-D configuration are the result of the vernier engine system backup to the SPS throughout the entire mission, while the LEM propulsion will provide this backup to the LEM separation phase only. The vernier engines may also be used to provide pitch and yaw control in the event of a SM RCS failure.

CONCLUSION

Evaluation of each of the proposed Block II configurations indicates that Block II-D would be the optimum configuration for reliability. The effects of reducing the LOR mission length from 14 to 10 days provided the greatest reduction in mission and crew losses. However, there was significant improvement of both mission success and crew safety reliabilities provided by the vernier engine backups to the SPS. A more rigorous study of propulsion backups follows this section.

The effect of the LEM backup to the SPS, while not clearly shown in the comparative analysis of the configurations, significantly increases the crew safety reliability. However, a potential of more significant reductions in crew losses exists if compatible interfaces are developed between the CSM and LEM electrical power and environmental control systems. The compatibility of these subsystem interfaces could result in the backup of these subsystems in all the abort missions occurring prior to LEM separation.

PROPULSION BACKUP TRADE-OFF STUDY

This study was conducted to determine the solution of two problem areas existing on the spacecraft. The primary problem area comes from the proposal to fly a nonfree return trajectory to the moon, effecting an equivalent of a 1231-pound reduction of dry CSM launch weight, rather than the free return trajectory presently proposed. The effect of the nonfree return trajectory on reliability is that it precludes the safe return of the crew in the event of a SPS failure during translunar coast; where as, for a similar occurrence on a free return trajectory, the SM RCS could perform the necessary midcourse corrections to return the crew safely. The second problem area is the SPS; this system has the greatest potential for single-point failures of any system in the command service module. A single-point failure is that condition where the failure of a single part will result in crew or mission loss. A need for a backup to this system is vital to achieve adequate crew safety reliability for the Apollo spacecraft.

To evaluate solutions to these problems, a comparative analysis of seven unique combinations of propulsion backup and their effects on mission and crew losses in a 10-day LOR mission was conducted. Both free return and nonfree return trajectories were considered for each backup configuration. The mission profiles, as well as the configuration data outlined in the Model section of this report, were used in this analysis.

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Discussion

The baseline mission used to compare the reliability effects of the backup configurations analyzed in this study was the 10-day LOR mission, having a free return trajectory. The backup configurations considered were combinations of the LEM propulsion stages (i.e., descent engine and/or ascent engine) and the use of the vernier engine system on the service module. The combinations of propulsion backup were augmented by either the parallel feed system to the SPS engine or a SPS fuel dump capability.

The parallel feed system is of value in eliminating the dynamic instability problem occurring when the LEM ascent engine is used to apply a ΔV to the command service module when the SPS fuel tanks are partially empty. Since it was assumed that the SPS fuel tanks would be resized to meet the specific fuel requirements, this problem does not occur in translunar coast aborts. Thus, the advantage of the parallel feed system would only be seen in aborts from lunar orbit prior to LEM separation because until the lunar orbit injection is performed, the SPS tanks are relatively full.

The value of the SPS fuel dump capability is realized in most mission aborts when the SPS is inoperable; the vehicle mass is reduced by dumping fuel overboard. With the vehicle's mass reduced, an increase in velocity per pound of fuel expended in a propulsion maneuver is realized. Even when the SPS propulsion fuel is being used by the vernier engine system, this dump capability is of value, because the limiting factor in the use of the vernier engines for a mission abort is the engine burn time and not the fuel availability.

Definitions of the propulsion backup configurations considered and their effects on the mission and crew losses are found in Table 5-3. The numerics defining the mission and crew losses for the configurations are presented as changes from the baseline numerics. These numerics represent both reductions and increases in losses per million missions. As previously indicated, the change to a nonfree return trajectory using the present CSM configuration increases the number of crew losses by 2000 per million missions, which represents the number of mission aborts with an inoperable SPS during the translunar coast phase of the mission.

Configuration 2, Table 5-3, using the LEM descent engine as propulsion backup, does not improve mission success, because it is not available after the minimum mission objectives are achieved. However, a significant reduction in the crew losses is realized in the missions having free and nonfree return trajectories. This reduction in crew losses represents the number of times the LEM descent engine successfully backed up an inoperable SPS, plus the number of crew losses avoided by shorter abort mission lengths from lunar orbit. The LEM descent stage does not effect shorter abort mission lengths during translunar coast because: either the SPS is operable and

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Table 5-3. Propulsion Backup Trade-Off Summary

Apollo LOR Mission Configuration	Free Return		Non-Free Return	
	ΔQ Mission Success per 10^6	ΔQ Crew Safety per 10^6	ΔQ Mission Success per 10^6	ΔQ Crew Safety per 10^6
1. Present system with CM RCS backup	288,280*	43,400*	0	+2,070
2. Present system with LEM descent backup	0	-1,970	0	-1,150
3. Present system with LEM descent and ascent	0	-1,970	0	-1,970
4. Present system with LEM descent and ascent with parallel feed	0	-1,970	0	-1,970
5. Present system with LEM descent and ascent with dump	0	-1,970	0	-1,970
6. Present system with vernier engines with dump	-1,140	-3,960	-1,140	-3,960
7. Present system with vernier engines	-1,140	-3,960	-1,140	-3,110
8. Present system with LEM descent and ascent and vernier engines with dump	-1,140	-3,824	-1,140	-3,820

*Baseline

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has sufficient fuel to return at a speed up to the maximum entry velocity constraints, or the SPS is inoperable, and the LEM descent stage has insufficient fuel to effect a maximum velocity abort.

The increase in crew losses for the mission having a nonfree return trajectory when utilizing the LEM descent stage for propulsion backup is due to the inability of the LEM descent stage to back up an inoperable SPS after the spacecraft enters the lunar sphere of influence (approximately 50 hours after translunar injection) during the translunar coast phases of the mission. This inability is due primarily to the lack of sufficient fuel in the LEM descent stage to overcome the gravitational effects of the moon on the spacecraft.

Configurations 3, 4, and 5, shown in Table 5-3, which utilize both the LEM descent and ascent stages for SPS backup, show no effects on mission losses but a significant reduction of crew losses. The addition of the LEM ascent stage, which provides approximately 700 feet per second in ΔV to the spacecraft, is sufficient to overcome the lunar gravitational forces affecting the translunar propulsion backup capability in a nonfree return trajectory. The slight variation in the reduction of crew losses among these configurations results from the variation of abort mission lengths.

Configuration 6, Table 5-3, containing both the vernier engine system and the SPS fuel dump capability, results in the reduction of both mission and crew losses. The reduction of mission losses is the result of the ability to abort successfully after achieving minimum mission objectives. The decrease in crew losses in utilizing the vernier engines to abort also reflects the fact that the vernier engines have a higher reliability than the LEM propulsion stage. This high engine reliability can be expected from the lower thrust engines used in the vernier engine system.

Configuration 7, Table 5-3, using the vernier engine system without the SPS fuel dump capability, reflects the same gains in mission success and crew safety reliability as configuration 6, with the exception of the crew safety reliability using a nonfree return trajectory. This decrease in crew safety reliability of the mission using a nonfree return trajectory indicates the need to dump SPS fuel overboard to overcome the lunar gravitational force during mission aborts from within the sphere of lunar influence during the translunar coast phase of the mission.

Configuration 8, Table 5-3, contains both the vernier engine system and the LEM propulsion stages as backups to the SPS, augmented by the SPS fuel dump capability. This configuration, having excessive ΔV capability during the translunar coast period of the mission, shows equal reductions in mission and crew losses for missions using either free return or nonfree return trajectories.

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While the reduction in mission losses is the same as in the configurations using only the vernier engines, the reduction of crew losses is not as great as experienced in the configuration containing the vernier engine system with the SPS fuel dump capability. This difference again reflects the lower reliabilities of the LEM propulsion stages which were necessary to accommodate a ground rule to carry the LEM with the CSM up to service module separation. It is felt that in carrying LEM back in the abort missions as often as possible, the potential crew safety reliability gains realized by utilizing the LEM electrical power system and environmental control system as backup to those of the command service module will increase the reduction in crew losses provided by this configuration over all of the others considered. The influence of these system backups was not included in this analysis because of the absence of pertinent LEM data.

Conclusions

The results of these propulsion backup analyses, summarized in Table 5-3, indicate that although the configuration containing the vernier engine system augmented by the SPS fuel dump capability with LEM ascent and descent engines provides the greatest reduction in both mission and crew losses, a configuration containing the vernier engine system with the LEM descent stage would be the optimum configuration from system complexity and reliability considerations. This reasoning results because without the LEM descent stage as backup to either an operable or inoperable SPS, the LEM could not be carried back to the point of service module separation for those mission aborts occurring prior to the LEM separation phase in lunar orbit. The advantage of carrying LEM back during these aborts has been discussed in the Mission Configuration section of this report. The deletion of the SPS fuel dump capability and the LEM ascent stage from the backup configuration is a result of using the vernier engine system ΔV capability of approximately 1700 feet per second to assist in abort missions occurring within the lunar sphere of influence during the translunar coast having nonfree return characteristics. Thus, the recommended propulsion backup configuration containing the vernier engine system and the LEM descent stage provides the greatest potential in reliability growth with the minimum system complexity for missions with either free return or nonfree return trajectories.

FAULT-TREE ANALYSIS

The fault-tree method of analysis provides a graphic display of fault sequences which can cause a critical event. A measure of the system safety level also may be provided. While the technique is directed towards a specific situation and embodies certain assumptions, it appears that benefits may be derived by applying it to the Apollo program. An investigation has been started to determine its applicability to Apollo. Initially, modifications required to apply the technique to an evaluation of Apollo systems safety will be defined. This will include expansion of the technique to encompass other than launch modes. This phase of the study is scheduled for completion during the next quarter.

HUMIDITY, OXYGEN, AND CONTAMINANTS PROBLEM

The environmental test procedures for humidity, oxygen, and corrosive contaminants have been completed. These procedures were developed for the electrical and electronic equipment within the command module.

The study used three approaches to determine the optimum test procedures: sequential environmental testing, combined environmental testing, and sequential-combined environmental testing. The last was determined to be the optimum approach.

The test procedures require sequential-combined testing of a single article in a 1-percent salt fog solution for 48 hours, followed in 1 hour by 50 hours of dry oxygen at 5 psia. Upon completion of the dry oxygen exposure, the test article will be exposed to 240 hours of combined oxygen and humidity. The test article will have continuous power on during the salt fog tests. During the dry oxygen and the combined oxygen humidity tests, the test article will be operated in the normal mission modes. All equipment will be turned on and off during the test to induce condensation by cooling, simulating mission operations.

CIRCUIT ANALYSIS

The following studies of circuit analysis by computer were performed during the last quarter.

CIRCUIT AND FAILURE MODE EFFECTS ANALYSIS PROGRAM (CFMA)

During this program, each circuit component will be individually opened and shorted. For each case, the output quantities (mode voltages and power stresses) are calculated and tabulated. Cathode ray tube plots can be made available which will show, for each output quantity, the number of failures occurring, as plotted against the circuit input parameters. A clear-cut method is thus available for determining the number of failure modes by which each output quantity can fail, as well as the total circuit failure modes and their causes in general.

Additional features of this program are its ability to accept linear approximations of manufacturer's published characteristic curves for diodes and transistors. Given this information, the computer will check the quiescent state of the circuit against the input equivalent circuit and parameters. If the two do not agree, the computer will iterate on the linear curves until the proper operating state of the circuit is determined. All necessary matrix equations can be derived by the CODE program.

ITERATION SUBROUTINE (ITER)

This deck can be used along with the VINIL and SCAN programs. The function of this iteration subroutine is similar to the routine which accepts linear curves for diode and transistor characteristics in the CFMA program. The main difference is that subroutine ITER can accept as much as ten straight-line iteration segments to approximate a diode or transistor curve. ITER will enable the analysis program in use to sweep from left to right along each operating state (line segment) of each nonlinear element in the circuit. Along each straight-line segment, the computer will determine if the circuit solutions in that operating condition imply results that agree with the original assumption by the computer of the circuit being in that particular operating state. If not, the computer stores the difference in memory and goes on to another straight-line approximation until the assumed and calculated results agree. This is done for each nonlinear element in the circuit until all operating states are determined.